

TASK 5

INITIAL POST-PROJECT EVALUATION REPORT

KNIGHTS FERRY GRAVEL REPLENISHMENT PROJECT

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EXECUTIVE SUMMARY

Study objectives for Task 5 of the Knights Ferry Gravel Replenishment Project (KFGRP), CALFED Project #97-N21, were to compare the spawning and incubation habitat conditions for fall-run chinook salmon (*Oncorhynchus tshawytscha*) at 18 project sites, seven control sites, and a 1997 California Department of Fish and Game project site. Three experimental gravels were used for restoration, two consisted of Stanislaus River rock cleaned with different sizes of screens and a third consisted of Tuolumne River rock. Each type of gravel was placed at six of the KFGRP project sites between 4 August and 24 September 1999. After the restoration gravel had been placed, the elevation of the streambed was surveyed in a grid pattern at each study site in August and September 1999. Monitoring included periodic surveys to map fall-run chinook salmon redds and measure intragravel dissolved oxygen (D.O.) and vertical hydraulic gradient in artificial redds between 18 October 1999 and 9 February 2000. The permeability of the undisturbed gravel was measured in October and September 1999, again in February 2000 following a series of intensive rain storms, and a third time between 27 June and 5 July 2000 following five months of reservoir releases between 1,500 and 3,500 cfs. The permeability of five chinook salmon redds was measured in December 1999. Intragravel and surface water temperatures were monitored at 30-minute intervals beginning 18 October 1999 until the thermographs were retrieved between 6 February and 5 July 2000. Minor rain storms occurred periodically during most of the study period, whereas the last set of measurements made in early February followed an intensive storm that greatly increased turbidity and flows up to about 1,180 cfs.

The density of redds at the study riffles was significantly correlated with both the distance downstream from Goodwin Dam and the size and source of the restoration gravel. *F*-tests that compared regressions of redd density versus distance downstream indicated that redd densities at sites with Stanislaus River rock washed with a 3/8-inch screen were about 70% higher than redd densities at sites where similarly sized Tuolumne River rock was added; the difference was significant at a probability level of 0.073. Although redd densities were about 29% higher at the sites with Stanislaus River rock cleaned with a 1/4-inch screen than at sites with Stanislaus River rock cleaned with a 3/8-inch screen, the difference was not significant ($P \geq 0.370$).

The elevation of the natural riffle's crest as measured under pre-project conditions had no measurable effect on downwelling rates in artificial redds, intragravel D.O. concentrations or the density of redds. Vertical hydraulic gradient (VHG), which is the measurement of downwelling rate used in this study, was near zero at all artificial redds in both project riffles and control riffles, regardless of the elevation of the riffle's crest. Furthermore, intragravel D.O. concentrations were near saturation at most project riffles regardless of the elevation of the riffle's crest. It was not possible to conduct a statistical analysis of the density of redds in riffles with differing crest elevations due to the low number of replicates and the confounding influences of gravel type and distance downstream. However, there were almost no differences in redd density between the high-crested, moderate-crested, and low-crested riffles near Lovers Leap that all received Stanislaus River rock washed with a 3/8-inch screen. These data suggest that redd densities do not differ between restoration riffles created by adding gravel to extensively mined channels, naturally flat channels, or the natural tails of pools.

A critical review of the literature on salmonid egg survival to emergence indicates that estimates

of egg survival to emergence based on habitat measurements, such as intragravel D.O. concentrations, apparent velocity, permeability, and the concentration of substrate fines, should be viewed with caution. Comparisons among previous studies suggest that egg survival to hatching is substantially affected by the adhesion of fine sediment to the egg's membranes although this presumed influence has not been quantified under field conditions. Furthermore, studies of alevin emergence rates have either used abnormally healthy alevins tested under laboratory conditions or failed to accurately estimate the initial number of viable eggs or the number of alevins that escaped from natural redds capped with netting, thereby making it impossible to determine the accuracy of the egg survival to emergence estimates. Therefore, it is recommended for future studies that egg survival to emergence should be measured directly by planting eggs to determine the percentage of eggs that survive to hatching and also by determining emergence rates in natural redds, both at single and superimposed redds.

The intragravel D.O. concentration at the project sites was significantly greater than the concentrations measured at the control sites in mid-December 1999, which is about the time when the eggs began to hatch, and in early February 2000, which is when most eggs had hatched. The mean D.O. concentration was 10.7 ppm at 68 artificial redds in the restoration sites and 9.3 ppm at 27 artificial redds in the control sites in mid-December. The mean D.O. concentration was 11.1 ppm at 31 artificial redds in the restoration sites and 9.7 ppm at 16 artificial redds in the control sites in early February 2000. The D.O. concentrations measured at 98.5% of the artificial redds in project riffles were probably sufficient to maximize the survival of chinook salmon eggs to hatching (≥ 8.0 ppm), whereas the D.O. concentrations measured in the control riffles would have produced high rates of survival at only 77.8% to 84.6% of the artificial redds. Furthermore, the high D.O. concentrations at the project riffles would have produced larger and healthier alevins that would be better able to emerge and compete for food after emergence than the fry produced at the control riffles.

Streambed permeability in the undisturbed beds of the riffles, which was used as a measure of intragravel flow for this study, was significantly greater at the project riffles where the restoration gravel was at least 12 inches deep than at the control sites throughout the fall 1999 incubation period. Furthermore, the permeability of the riffle bed was sufficient to nearly maximize ($\geq 80\%$) the expected survival of chinook salmon eggs to emergence based on laboratory studies at two-thirds of the locations sampled in the project sites in early February after several turbid rain storms. After most of the eggs had incubated and the flood control releases began in mid February 2000, permeabilities increased at most project riffles but declined significantly at the upstream half of many project riffles in the Lovers Leap reach (riffles R13-R20) to levels that are similar to those at the control sites. It is likely that fine sediment was deposited at high rates at the riffles near Lovers Leap because this is an area of relatively recent and extensive gravel and gold mining.

Monitoring intragravel water temperatures in artificial redds and surface water temperatures provided data that were useful for detecting the timing and relative magnitude of fine sediment intrusion and the upwelling of oxygen-poor groundwater. Intragravel water temperatures rapidly changed after installing the thermographs in mid October 1999 from closely matching surface water temperatures in magnitude and fluctuation to becoming elevated by 0.8 to 13 degrees Fahrenheit and relatively stable at six artificial redds. The intragravel dissolved concentration was usually below 8.0 ppm at these six sites. The changes at these artificial redds were not

related to changes in flow, storm runoff, or nearby redd construction. The site features suggest that the elevated and stabilized water temperatures resulted from fine sediment intrusion that decreased the ratio of surface flow downwelling to groundwater upwelling. Furthermore, the fine sediment intrusion probably resulted from the intragravel transport of fines within silty riffles during normal flow releases.

Intragravel water temperatures also became stabilized and slightly elevated at 44% of the artificial redds usually beginning on 15 February 2000, which was one day after 1,500 cfs flood control releases began. About half of these sites occurred near Lovers Leap, where bed permeabilities significantly declined after the flood control releases. In late June and early July 2000, the mean intragravel D.O. concentration at these sites, which was 7.7 ppm, was significantly lower than the mean intragravel D.O. concentration of 9.3 ppm which occurred at the sites where no temperature deviations occurred.

INTRODUCTION

This report presents the results of Task 5, the initial post-project spawning habitat studies in the lower Stanislaus River conducted in fall 1999 for the Knights Ferry Gravel Replenishment Project (KFGRP). The study objectives were to compare the spawning and incubation habitat conditions for fall-run chinook salmon (*Oncorhynchus tshawytscha*) at 18 project sites, seven control sites, and a California Department of Fish and Game (DFG) project site where gravel was added in 1997 in the upper Goodwin Canyon. A total of 13,000 tons of gravel was added to the 18 KFGRP sites between 4 August and 24 September 1999 (CMC 1999a). Three experimental gravels were used for restoration, two consisted of Stanislaus River rock cleaned with different sizes of screens and a third consisted of Tuolumne River rock. Each type of gravel was placed at six of the KFGRP project sites. All 26 study sites occur between the DFG upper Goodwin Canyon site (RM 58) and Oakdale (RM 40, Figure 1).

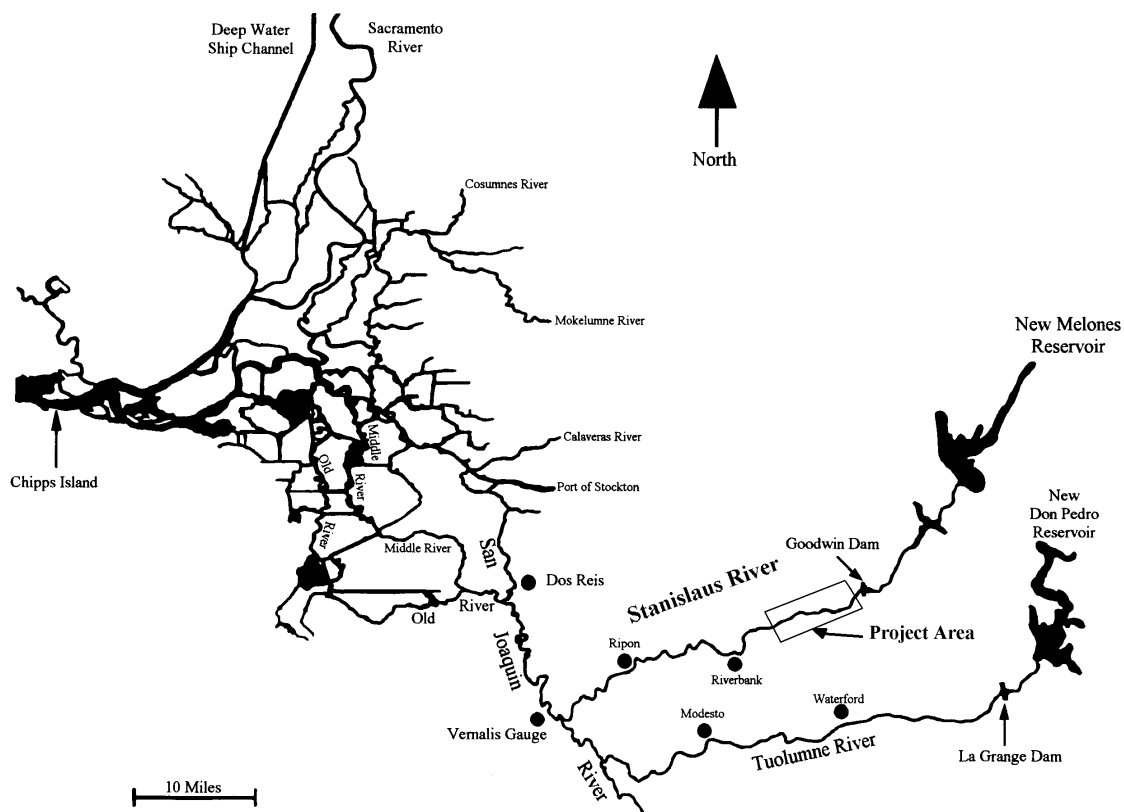


Figure 1. Map of the Sacramento-San Joaquin Delta showing the Stanislaus River, Goodwin Dam, and the project area.

Justification for the KFGRP was based on several studies. A Department of Water Resources (DWR 1994) study of 22 riffles between Goodwin Dam and Riverbank indicated that 45% of the riffles sampled had excessive levels of fines in substrate samples collected from the upper sections of the riffles where the salmon prefer to spawn. Redd surveys in 1994 and 1995

(Mesick 2001a) indicate that most chinook salmon spawned in the 12-mile reach between Goodwin Dam and the Orange Blossom Bridge (RM 46.9). These surveys also indicate that 73% of the salmon spawned upstream of the riffles' crests where the streambed sloped upwards (e.g., the tail of a pool). At 10 natural riffles between Two-Mile Bar (RM 56.6) and Oakdale where redd densities were relatively high in 1994 and 1995, intragravel dissolved oxygen (D.O.) levels were probably suboptimal between November 1995 and February 1996 due to the combined effects of decaying Asian clams (*Corbicula fuminea*) that were buried during redd construction, excessive fines, and the inflow of oxygen-poor groundwater, particularly after intensive rain storms (Mesick 2001a). Intragravel D.O. levels were less than 5 ppm at 15% of the piezometers in artificial redds and less than 8 ppm at 31% of the piezometer sites during five surveys in November and December 1995. Immediately after five intensive rain storms in early February 1996, D.O. levels declined to less than 5 ppm at 42% of the sites and to less than 8 ppm at 62% of the sites. Elevated intragravel water temperatures, an indicator of groundwater inflow, occurred at many of the sites where D.O. levels declined after the intensive rain storms. Although the survival of salmonid eggs has been extensively studied, it is not possible to accurately estimate egg survival based on measurements of substrate fines, D.O., or intragravel flow rates (Chapman 1988). A literature review of salmonid egg survival studies is presented in the next chapter.

The poor quality of spawning habitat in the Stanislaus River has resulted from the blockage of coarse sediment supply from the upper watershed by dams and from instream gravel mining downstream of Goodwin Dam from about 1940 to the 1970s (Mesick 2001b). The loss of upstream gravel recruitment has contributed to the armoring of riffles in Goodwin Canyon and the one-mile section immediately downstream of the Knights Ferry County Bridge. Downstream from there, many riffles were completely excavated by in-river gravel mining. Kondolf et al. (2001) estimated that 1,031,800 yd³ of gravel was extracted from the active channel between Goodwin Dam and Oakdale from 1949 to 1999. Surveys conducted by DFG (1972) in the 1960s suggest that about 55% of the channel between the Knights Ferry County Bridge and the Orange Blossom Bridge was repeatedly mined. Furthermore, a comparison between the DFG surveys conducted in the 1960s and surveys conducted in 1995 and 1996 (Mesick 2001a) suggest that the few riffles that were left untouched in the dredged reaches have since become armored and shortened (Mesick 2001b).

Escapement of fall-run chinook salmon to the Stanislaus River declined from an average of 15,000 fish from 1947 to 1954 to an average of 4,700 fish from 1955 to 1989, and then to an average of 737 fish from 1990 to 1998 (Mesick 2001b). While it is likely that water development and Delta exports contributed to this decline, the in-river gravel mining between 1940 and the 1970s probably was another contributing factor (Mesick 2001b). A stock-recruitment analysis for the Stanislaus River chinook salmon population from 1948 to 1995 suggests that recruitment initially increases as stock increases until stock reaches about 2,500 fish and then recruitment remains constant as stock increases (Mesick 2001b). This suggests that the habitat in the Stanislaus River can support the progeny of only 1,250 pairs of adult salmon.

To evaluate whether adding clean gravel to the streambed of the Stanislaus River improves spawning and incubation habitat, studies were designed to test ten hypotheses identified in the

KFGRP Ecological Monitoring Plan (CMC 1999b). There are two hypotheses on improving spawning habitat:

Hypothesis I-A: The density of fall-run chinook salmon redds will be higher in unconsolidated gravel in the project riffles than in the cemented gravel in the control riffles.

Hypothesis I-B: The higher the elevation of a riffle's crest, the greater will be the rate of surface water downwelling that presumably helps attract spawners.

There are three hypotheses on improving incubation habitat:

Hypothesis II-A: Adding gravel without fines to the streambed increases intragravel flow in redds.

Hypothesis II-B: Higher gradients of the streambed upstream of the hydraulic control at the riffle's crest result in higher rates of surface water downwelling that presumably increases intragravel dissolved oxygen concentrations.

Hypothesis II-C: The low percentage of fines in the project riffles will result in high intragravel D.O. concentrations relative to those at the control riffles, where the concentration of fines is high.

Other hypotheses were developed to improve the techniques required to restore spawning habitat. In summer 1994, DFG and DWR reconstructed two riffles, R27 and R28, in the Stanislaus River near the Horseshoe Road Recreation Area (RM 50.4 and RM 50.9) and another riffle just upstream of the Orange Blossom Bridge (RM 47.4) that were used by relatively few spawning chinook salmon. These three riffles were reconstructed by excavating the channel bed to a depth of 1.5 feet to remove gravel and silt, and replacing the excavated material with washed gravel, sized from 0.5 to 4 inches (Kondolf et al. 1996). The washed gravel was imported from the Blasingame Quarry near the Merced River and about 60% of the rock had sharp edges (Mesick 2001a). Only about 20% of natural gravel from the Stanislaus River had sharp edges (Mesick 2001a). Rock weirs were constructed at the upstream and downstream boundaries of each site to achieve the "necessary grade" of 0.2% to 0.5% and to retain the imported gravel during high flows. Redd surveys at these two riffles (R27 and R28) at the Horseshoe Road Recreation Area indicated that few salmon spawned in the added gravel through fall 1997, whereas redds were observed in natural gravel adjacent to the added gravel (Mesick 2001a). After a 15-foot-long, two-foot high berm of natural gravel had been deposited across the crest of Riffle R27 in spring 1997, 16 redds were observed in the gravel berm whereas only one redd was observed in the restoration gravel in fall 1997.

In 1996 and 1997, DFG added about 2,000 tons of gravel obtained near the Stanislaus River to several sites in upper Goodwin Canyon where gravel was scarce. The added gravel, obtained near the Stanislaus River, contained very little angular rock, and ranged from 0.35 to 5 inches in diameter. It was added to the undisturbed streambed in pools and in bars across shallow areas. Many salmon spawned in this new gravel in the first season (Mesick 2001a).

The following three hypotheses were developed to test why the salmon utilize some restoration sites but not others:

Hypothesis III-A: Restoration gravel obtained from near the Stanislaus River will be used by more Stanislaus River chinook salmon than will gravel obtained from another watershed.

Hypothesis III-B: Restoration gravel between 3/8 inch and 5 inches will produce higher gravel permeabilities than will gravel between 1/4 inch and 5 inches.

Hypothesis III-C: Restoration gravel between 1/4 inch and 5 inches will attract more spawners than will gravel between 3/8 inch and 5 inches.

The following two hypotheses were developed to test the effects of the streambed configuration on the useful life of the project.

Hypothesis IV-A: During high flows, high-crested riffles retain more gravel than moderate-crested riffles, which retain more gravel than low-crested riffles.

Hypothesis IV-B: Project riffles in mined channels will lose gravel at a faster rate than will project riffles adjacent to functional floodplains.

LITERATURE REVIEW OF SALMONID EGG SURVIVAL

The following discussion of the survival of salmonid eggs to emergence is separated according to the conditions that affect hatching of eggs and the conditions for the continued development and emergence of alevins.

SURVIVAL TO HATCHING

Numerous field and laboratory studies indicate that egg survival to hatching, which typically requires 40 to 50 days at 10 C (50 F), depends on an adequate concentration of D.O., a sufficient rate of intragravel flow in the egg pocket, and suitable water temperatures (Chapman 1988; Kondolf 2000). Excessive concentrations of substrate fines smaller than 1 mm in diameter are usually correlated with reduced D.O. and intragravel flow (Chapman 1988; Kondolf 2000).

Although laboratory studies clearly indicate that the D.O. requirement of eggs is typically greatest immediately prior to hatching before the gills have become functional (McNeil 1966), the quantification of D.O. and intragravel flow requirements in the natural stream varies considerably among studies. One difficulty in this analysis is that small clay-sized particles adhere to an egg's membrane (Stuart 1953) thereby reducing its ability to absorb D.O. This effect is shown in a comparison of three studies of steelhead trout egg survival relative to D.O. concentration. A laboratory study by Silver et al. (1963), during which eggs were incubated on clean, porous ceramic plates under highly controlled levels of D.O. and flow, indicates that survival was high (about 80%) at D.O. levels of at least 2.5 mg/l (Figure 2). In contrast, a field study by Coble (1961), during which eggs were placed in plastic mesh sacks with gravel, indicates that egg survival gradually declined as D.O. declined from 9.2 mg/l to 2.6 mg/l (Figure 2). Another field study by Phillips and Campbell (1962), during which eggs were placed in perforated metal boxes with glass beads, indicates that no eggs survived at D.O. levels at or below 7.2 mg/l (Figure 2).

Studies with other salmonid species show similar results. Eggs of chum salmon (*O. keta*; Alderdice et al. 1958), chinook salmon (Silver et al. 1963), and coho salmon (*O. kisutch*; Shumway et al. 1964) incubated under clean laboratory conditions survived to hatching at high rates at D.O. concentrations as low as 2.0 to 2.5 mg/l. Chum salmon eggs that were deposited in natural redds in an experimental stream channel with washed gravels also survived at relatively high rates (50%) at D.O. levels as low as 2.5 mg/l (Koski 1975). Conversely, the survival of coho salmon eggs incubated in natural streams either in natural redds (Koski 1966) or in experimental chambers (Phillips and Campbell 1962) were reduced at D.O. concentrations below 9.0 mg/l and 8.3 mg/l, respectively. Although the adhesion of fines to the egg's membranes was not evaluated in the field studies, it is the most likely explanation for why eggs require greater concentrations of D.O. in natural streams than in a laboratory or in washed gravel.

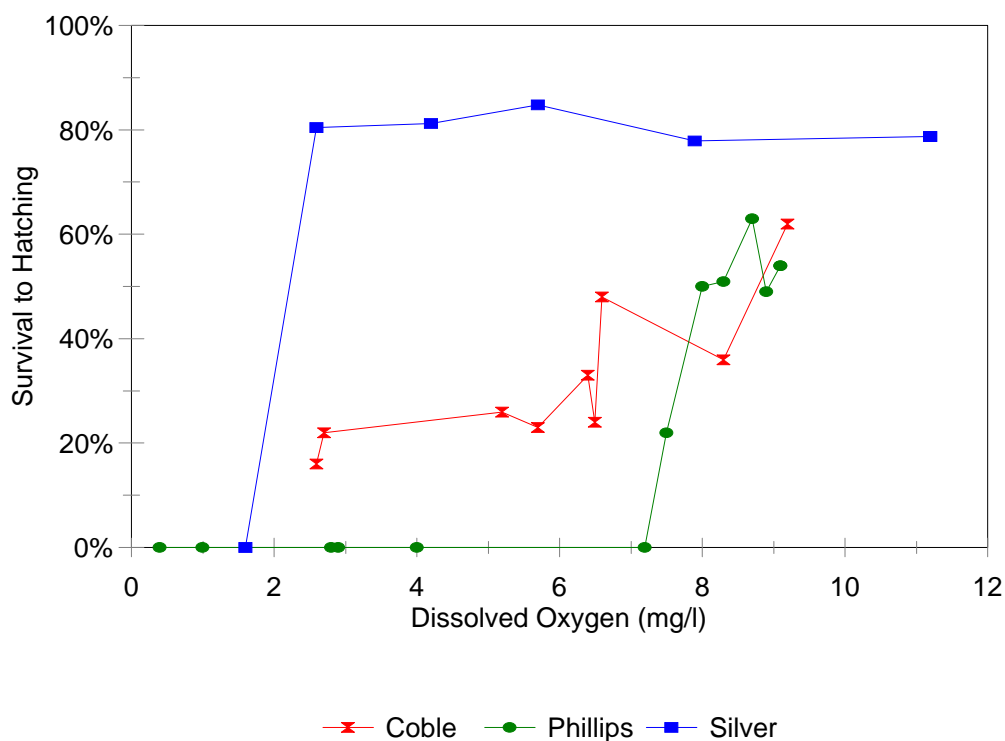


Figure 2. The relationship between dissolved oxygen concentration and the survival to hatching of steelhead trout eggs during a laboratory study by Silver, Warren, and Doudoroff (1963) and two field studies, one by Coble (1961) and the other by Phillips and Campbell (1962).

The D.O. requirement of chinook salmon eggs has not been accurately determined under natural field conditions. Although Gangmark and Bakkala (1960) studied the survival of green chinook salmon eggs to hatching in artificial redds in Mill Creek, California relative to D.O. concentrations, their results are questionable because individual test results were not presented and the methods were not fully described. Instead the authors referred to their earlier studies for a description of the methods when handling mortalities averaged 53% because the eggs were not allowed to water harden before handling and because fungal infections caused by egg contact with the plastic mesh net bag resulted in mortality (Gangmark and Broad 1955). Furthermore, an evaluation of a portion of their raw data presented in Gangmark and Bakkala (1958) indicated that they obtained a poor relationship between survival and D.O. concentration, possibly due to variable rates in handling mortality among replicates.

Without better direct evidence, it was assumed for this report that chinook salmon eggs have a relatively high D.O. requirement compared to coho and chum salmon and steelhead trout since chinook salmon produce relatively large eggs. Large eggs generally require high D.O. concentrations because they have a relatively small ratio of surface to volume (Beacham and Murray 1985).

In addition to the effects of low D.O. concentrations on survival of eggs to hatching, any reduction in D.O. below the saturation level results in slowly developing embryos that emerge at a small size and prior to the absorption of all yolk (Phillips and Campbell 1962; Silver et al. 1963; Shumway et al. 1964; Mason 1969; Wells and McNeil 1970; Koski 1975). It is likely that small alevins are relatively weak and less able to emerge through sand layers covering the egg

pocket than are large relatively healthy alevins incubated at high D.O. concentrations. Furthermore, Mason (1969) reported that small coho salmon fry subjected to low D.O. levels during incubation could not compete successfully with larger fry and emigrated from experimental channels. Chapman (1988) suggested that any reduction in D.O. levels from saturation probably reduces survival to emergence or post-emergent survival.

Intragravel flow is also correlated with egg survival. Intragravel flow is measured as either permeability or apparent velocity during egg survival studies. Permeability is the ease with which water passes through gravel and depends on the composition and degree of packing of the gravel and viscosity of the water (Pollard 1955). Apparent velocity is the horizontal vector of interstitial flow and is a function of permeability and hydraulic gradient (Pollard 1955; Freeze and Cherry 1979). It is measured as the rate of flow through a standpipe, which is called apparent yield, divided by the porosity of the surrounding gravel. The actual velocity of flow through interstitial spaces, which is called the true or pore velocity, is faster than the apparent velocity because flow travels around substrate particles whereas apparent velocity assumes that the flow path is linear. Laboratory studies, such as Silver et al. (1963) that incubate eggs without a gravel medium, measure true velocity whereas all field studies measure apparent velocity with standpipes.

Steelhead trout and coho salmon egg survival to hatching in natural streams has been correlated with apparent velocity, but not as strongly as with D.O. concentration; whereas there were no correlations with permeability (Coble 1961; Phillips and Campbell 1962). The size of coho salmon and steelhead trout embryos at hatching was reduced at low velocities, regardless of D.O. concentration in the lab (Shumway et al. 1964); whereas steelhead trout and chinook salmon egg survival was not correlated with true velocity under the same laboratory conditions (Silver et al. 1963). Koski (1966) reported that survival to emergence of coho salmon eggs in natural redds was not correlated with a permeability index (ml/sec). Sowden and Power (1985) reported that rainbow trout egg survival in a groundwater fed stream was strongly correlated with D.O. and apparent velocity, but not with the percentage of fines less than 2 mm, the geometric-mean particle size, or the fredle index. Although egg survival and apparent velocity have been highly correlated in several studies, there is no consistent critical apparent velocity relative to survival, possible due to the influence of different levels of D.O. and the adhesion of clay-sized particles to the egg's membrane among the studies. The results of five studies are listed below as evidence that the critical apparent velocity necessary for high rates of egg survival can vary from 50.9 ft/hr to 0.65 ft/hr depending on the D.O. concentration.

- Reiser and White (1988) reported that chinook salmon egg survival to hatching was highly correlated ($r = 0.797$) with apparent velocity and the percentage of two size classes of substrate fines during laboratory tests that maintained D.O. levels between 6.2 and 7.7 mg/l. These results suggest that at low D.O. levels tested, apparent velocity less than 50.9 ft/hr (1,550 cm/hr) resulted in reduced egg survival. They also reported that fines less than 0.84 mm in diameter affected survival to a much greater degree than did sediment between 0.84 and 4.6 mm in diameter, presumably due to a greater influence on intragravel flow.
- Deverall et al. (1993) reported apparent velocities in natural chinook salmon redds exceeded 16.4 ft/hr (500 cm/hr) at 45 of 49 redds in the Waitaki River, New Zealand and that egg survival to hatching was between 75 and 98% at three redds where apparent velocity ranged between 6.56 ft/hr (200 cm/hr) and 9.84 ft/hr (300 cm/hr) and D.O. levels were near saturation.

- Gangmark and Bakkala (1960) reported that the mean survival to hatching for green chinook salmon eggs planted in 220 artificial redds in Mill Creek, California exceeded 87% where apparent velocity was at least 1.5 ft/hr and D.O. exceeded 5 mg/l. Mean survival was 67% at 14 sites where apparent velocity ranged between 0.5 and 1.0 ft/hr during the same study. However, the results of their study are questionable because individual test results were not presented and the methods were not described (see the above discussion on egg D.O. requirements).
- Coble (1961) reported that steelhead trout egg survival to hatching was high, 48 to 62%, at artificial redds with mean apparent velocities that exceeded 1.52 ft/hr (46.5 cm/hr) and mean D.O. levels greater than 6.4 mg/l.
- Phillips and Campbell (1962) reported that steelhead trout egg survival was high, 49 to 63%, in artificial redds with apparent velocities that exceeded 0.65 ft/hr (20 cm/hr) and mean D.O. levels that exceeded 8.3 mg/l.

It is evident from these studies that the critical level for apparent velocities decreases as D.O. levels increase.

Water temperature during egg incubation has been suggested to be a significant factor affecting both egg development rates and mortality for chinook salmon in the Central Valley. The effects of temperature exposure on egg development and mortality has been investigated by Seymour (1956) and Alderdice and Velsen (1978). Results of laboratory investigations conducted by Seymour (1956) showed a rapid increase in chinook salmon egg mortality as temperatures increased above 57 F. Alderdice and Velsen (1978), who reviewed the available literature, estimated that the upper temperature limit for 50% mortality of chinook salmon eggs was near 61 F. Healey (1991) suggested that although chinook normally begin spawning in late summer when temperatures are near 61 degrees Fahrenheit (16 C), temperatures are falling rapidly at this time of year and the eggs are probably not exposed to near lethal temperatures for long.

Chinook salmon egg survival also declines at water temperatures below 42 degrees Fahrenheit (5.6 C) and mortality is about 100% at a constant temperature of 35 degrees Fahrenheit (1.7 C; Leitritz 1959). Eggs can tolerate temperatures below 42 degrees Fahrenheit for about 6 days without mortality (Leitritz 1959). Gangmark and Bakkala (1958) reported water temperatures between 34 degrees Fahrenheit and 36.5 degrees Fahrenheit in January 1957 in artificial redds with planted eggs in Mill Creek, the North Fork of Mill Creek and the Sacramento River. The duration of the cold temperatures was not reported but there was no indication that egg survival rates were affected.

SURVIVAL TO EMERGENCE

After hatching, the young salmon called alevins remain buried in the gravel for an additional period of development during which time nutrition is provided by absorption of the yolk sac. The period of alevin development is estimated to be between 35 and 55 days (mean 47 days) at 10 to 13 C based on the timing from redd completion to peak emergence at five redds (numbers 3, 4, 5, 8, and 11) with high emergence rates and a well defined emergence peak in the Tuolumne River in fall 1988 (EA 1992) and the assumption that the period of egg incubation ranged between 40 and 50 days. After yolk sac absorption by the alevins has been completed, the young salmon, referred to as “button-up fry”, begin the process of emerging from the gravel.

Fry emergence for fall-run chinook salmon typically occurs between January and March, although there can be considerable variation in the timing of fry emergence based upon the seasonal timing of successful spawning and environmental conditions (e.g., water temperature) during egg incubation.

Koski (1966) reported that a majority of mortality in redds was caused by the inability of alevins to emerge. He found numerous dead coho salmon alevins that were completely buttoned-up but extremely emaciated at a depth of 8 inches. Beschta and Jackson (1979) showed that in a flume, fines 0.5 mm in diameter tend to form a barrier in the upper 10 cm of the gravel bed that “seals” against intrusion of fines into the egg pocket but also creates a barrier to emergence. This barrier has been described in salmon redds as a mixture of coarse sand and fines 6 to 12 inches above the egg pocket (Hawke 1978) that has a geometric mean diameter (d_g) that was lower than the substrate above and below the middle layer (Platts et al. 1979). Bams (1969) reported that when sockeye salmon alevins confronted a sand barrier, they “butted” upward to loosen sand grains and form an open passage to the substrate surface. Koski (1966) reported that the number of days for the first coho salmon alevins to emerge was unaffected by the amount of fines, but that the total duration of emergence for all alevins was longer in redds with high percentages of fines.

Quantification of alevin entombment relative to the amount of fines has been difficult. Researchers that evaluated emergence rates by capping natural redds with nets, such as Koski (1966, 1975), Tagart (1976), and EA (1992), did not estimate egg viability, fertilization success, the loss of eggs during deposition in the egg pocket (Young et al. 1990), or escapement of fry that migrate under the trap’s netting (Garcia De Leaniz et al. 1993) and so they cannot accurately estimate egg survival to emergence (Young et al. 1990). Laboratory studies of the effects of various sand concentrations on emergence rates, such as those by Shelton and Pollock 1966, McCuddin (1977), Tapple and Bjornn (1983), Phillips et al. (1975), tested the ability of large, healthy alevins to emerge under high concentrations of sand, an abnormal condition considering that high concentrations of sand typically result in low D.O. levels and small, weak alevins. These researchers used laboratory troughs with washed gravel and maintained high D.O. levels and either provided high apparent velocities during egg incubation (McCuddin 1977) or planted eyed-eggs (Shelton and Pollock 1966; Tapple and Bjornn 1983) or alevins (Phillips et al. 1975) incubated under optimum conditions. Therefore, their results would predict abnormally high emergence rates if D.O. levels are low. These studies reported that a range of substrate particle sizes, including those ≤ 0.85 mm (Shelton and Pollock 1966), ≤ 3.3 mm (Koski 1966), ≤ 4.67 mm (Tapple and Bjornn 1983), and ≤ 6.4 mm (McCuddin 1977) affect entombment rates of alevins.

The quantification of the effect of a sand-silt barrier on entombment of alevins is difficult due to the fragile nature of the barrier. Driving probes to extract freeze cores from egg pockets or driving standpipes into the egg pocket to measure permeability disrupts the sand-silt barrier (Beschta and Jackson 1979). Platts et al. (1979) used a battery of probes to extract a frozen but intact egg pocket that weighed 620 kg; only one was sampled presumably due to the difficulty of working with such a heavy sample.

SUMMARY

Salmonid eggs, including those of chinook salmon, require high concentrations of D.O. near the saturation level for the development of large, healthy alevins. Suspended sediment that adheres to the egg's membrane probably reduces the ability of the egg to absorb D.O. and thereby increases mortality and development of healthy alevins. Considering that natural riffles in the Stanislaus River are very silty and turbid storm runoff frequently occurs during incubation, it is likely that few chinook salmon eggs in the Stanislaus River survive at D.O. concentrations below 8 to 9 mg/l and that the size and health of alevins are reduced at D.O. concentrations below about 11.5 mg/l. High intragravel flow rates can offset the effects of low D.O. concentrations, but only to a small degree.

Alevins require a pathway between the egg pocket and substrate surface that is not blocked by a thick layer of fine substrate particles to ensure successful emergence. Emergence rates appear to be quite variable in natural gravels, but the previous research has suffered from unrealistic laboratory conditions or difficulty of determining the initial number of viable eggs and the number of alevins that escape from natural redds capped with netting. However, it is likely that fry entombment can be a substantial source of mortality and that redd superimposition greatly reduces emergence in superimposed redds.

METHODS

Monitoring at the 26 study riffles between Goodwin Dam and Oakdale included (1) seven surveys of fall-run chinook salmon redds, intragravel dissolved oxygen (D.O.), and vertical hydraulic gradient, (2) two surveys of gravel permeability, and (3) one survey of streambed elevations between 18 October and 28 December 1999. One additional set of D.O. measurements were made at some sites on 26 January 2000 immediately following an intensive rain storm that greatly increased turbidity and flows up to about 1,180 cfs. Two additional sets of gravel permeability measurements were made, the first between 6 and 9 February 2000 and the second between 27 June and 5 July 2000. Intragravel and surface water temperatures were monitored continuously beginning 18 October 1999 until the thermographs were retrieved between 6 February and 5 July 2000.

During monitoring, streamflow releases were held constant at 375 cfs from 17 October through 10 December and then reduced to 350 cfs until 23 December 1999. Flow releases were further reduced to 325 cfs on 23 December 1999 and held constant until 12 February 2000. Flood control releases began at 1,500 cfs on 14 February 2000, peaked at 3,500 cfs for about 10 days in early March 2000, and then declined to 1,500 cfs between 20 April and 12 June 2000. Flows were reduced to 300 cfs on 21 June 2000 before the last set of permeability measurements were made.

STUDY AREA

The spawning reach for fall-run chinook salmon in the Stanislaus River is about 25.5 miles long and extends from Goodwin Dam, which is impassible for salmon, downstream to the town of Riverbank. During fall 1995 surveys, the riffles in the spawning reach were numbered and their locations marked on USGS quadrangles. In the 4.2 mile high-gradient canyon between Goodwin Dam and the Knights Ferry County Bridge, four riffles (TMA, TM1, TM2, and TM3) were identified near the Two-Mile Bar Recreation Area (RM 57). Downstream of the Knights Ferry County Bridge toward Riverbank, 106 riffles were marked during 1,500 cfs pulse flow surveys with a numbered 3-inch orange square that was nailed to either a tree or woody debris near the upstream boundary of each riffle. The riffle immediately upstream of the Knights Ferry County Bridge was identified as "R1." The other riffles were sequentially numbered in a downstream direction from there. During subsequent redd surveys conducted when flows were reduced to about 300 cfs, an additional 26 riffles and four small gravel berms were identified. These areas were identified by adding a letter to the upstream riffle's number. For example, an unmarked spawning area downstream of Riffle R2 was called Riffle R2A.

From the 140 riffles and spawning areas identified in the spawning reach in 1995, 18 sites for gravel addition and 7 control riffles were selected for the KFGRP as shown on USGS quadrangle maps in Appendix 1. The 18 project sites were classified into three categories based on the height of the riffle's crest (Table 1 in Appendix 2). However, since the proposal was prepared during the summer of 1997, gravel movement occurred at several sites that changed the height of the riffle's crest. Besides the change in the riffle's crest, the original classifications were based on elevations measured on a single transect along the length of the riffle, which are not as useful as the contour maps made in August 1999 that show the topography of the entire streambed. Based on the August 1999 data, riffles R10, R14, and R19A were reclassified from moderate-

crested riffles to low-crested riffles, and riffles R13, R20, and R43 from low-crested riffles to moderate-crested riffles. Riffle R15 was reclassified from a high-crested riffle to a moderate-crested riffle. Spawner use and incubation conditions were previously monitored at KFGRP riffles TM1, R10, and R27 in fall 1995 (CMC et al. 1996) and at KFGRP riffles R10, R14, R29, R43, R58, and R78 in fall 1996 (CMC 1997).

Three different types of naturally rounded river gravel were placed at the 18 project sites between 4 August and 24 September 1999 (CMC 1999). One type consisted of gravel obtained near the floodplain of the Stanislaus River that had a natural mixture of 1/4 to 5 inch rock. This mixture was placed at riffles TMA, R12B, R14, R19, R28A, and R58. Another type consisted of the same Stanislaus River rock except that the sizes ranged between 3/8 and 5 inches. This mixture was placed at riffles R1, R12A, R13, R14A, R19A, and R57. The third type of gravel was obtained from the 7-11 Material gravel quarry adjacent to the Tuolumne River that ranged in size between 3/8 and 5 inches. This mixture was placed at riffles R5, R15, R16, R29, R43, and R78. The cumulative size distribution curves for these three gravel types are shown in Figure 3.

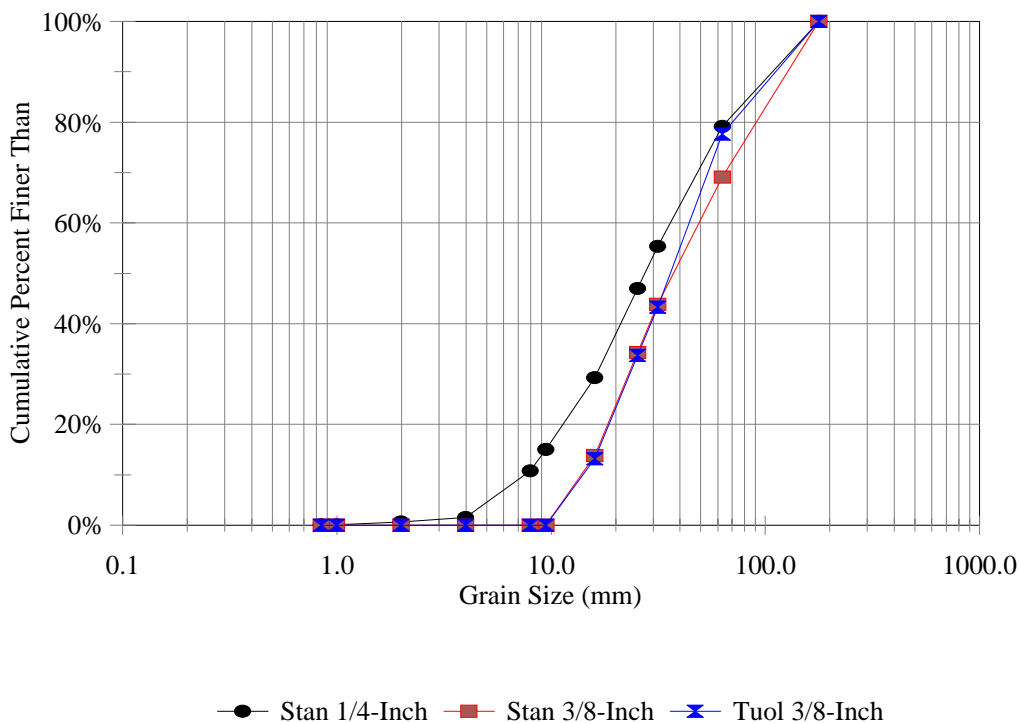


Figure 3. Cumulative size distribution curves for the three types of restoration gravel added to 18 project sites at the Stanislaus River in August and September 1999. Samples of 45 to 70 kg were collected of each type after the gravel had been washed and delivered to the sites, but prior to placement in the river.

SPAWNER USE

Redds were identified as disturbances in the substrate; they typically have a shallow pit or depression in the upstream half of the disturbed area and a mound of gravel at the downstream half of the disturbance called a tailspill. Most redds were approximately five feet wide by 10 feet long. After it appeared that a redd had been completed, a numbered 2-ounce lead sinker with orange flagging was placed in some of the redd's pits for identification. Marking was necessary because algal growth and sediment movement progressively made it more difficult to distinguish some of the redds within 10 to 20 days after the female stopped tending the redd.

Redd locations were initially mapped at each riffle by means of reference to either 2-foot long reinforcing bars driven into the ground or nails driven into trees on both sides of the river. A transect was established at each riffle by running a tape measure from the pin on the left bank (facing downstream) to the one on the right bank during all surveys. A second tape measure was then run from the redd to the transect so that both tape measures were perpendicular to each other. The distance in feet from the pin on the left bank along the transect to the tape measure from the redd was recorded as the station. The distance in feet from the redd to the transect and the direction (upstream or downstream) from the transect were also recorded. An x-y plot of the redd locations at each riffle was used during each survey to help identify old and new redds. The precise locations of all redds were surveyed using a Nikon DTM-310 total station between 4 and 15 December 2000. The stadia rod and prism were set at the middle of the upstream edge of the tailspill of each redd. The locations of all redds were plotted on a contour map for each site.

STREAMBED ELEVATION AND CONTOUR MAPPING

Relative elevations were measured between 24 August and 29 September 1999 in a 15- to 20-foot grid pattern, at major changes in grade along the streambank and channel bottom, and along transects established in November 1998 and September 1999 with a Nikon DTM-310 total station. Elevations of the tops of two to four 18-inch long, 3/4-inch diameter steel rods driven into the ground in August 1999 were measured at each site as reference points. These reference points, which are called backsights in the maps in Appendix 1, permitted comparisons of data sets collected at different total station locations or different years. Additional backsights were installed in September 1999 to provide at least three at each riffle. At some sites it was not possible to survey the entire riffle from one location due to the dense vegetation along the streambanks and so the total station was set at two locations, usually on opposite sides of the river. Photos were taken of each transect with the tape measure strung to help reset pins disturbed by vandalism, beavers, and high flows.

The Nikon total station has an angle accuracy of five seconds, which provides elevation measurements accurate to within 0.03 inches at a distance of 100 feet. The elevation data were collected as X, Y, Z coordinates that were stored electronically within the total station and then downloaded to a laptop computer. A software program called "Transit" was then used to convert the data into AutoCAD DXF format files. The DXF files were then imported into a software program called Terrain Version 3.1 developed by Softree Technical Systems to generate the contour maps in one-foot intervals. The contour maps show the location of the transects established in November 1998 and a few transects established at project sites in late August and

September 1999 that were needed to provide measurements over the newly placed gravel (Appendix 3).

New transects had to be established in late August and September 1999 after gravel placement occurred at nine project riffles, because the original transects did not traverse the main areas of gravel placement. The riffles where new transects were established include riffles R5, R12A, R13, R14A, R15, R16, R19, R19A, and R57. To compare pre-project bed elevations measured between 4 and 20 August 1999 with post-project elevations conditions measured between 24 August and 29 September 1999, it was necessary to estimate the pre-project elevations at the new transect locations. This was done by superimposing the pre-project map onto the post-project map (Appendix 3), matching the locations of all backsights and the original transect, and then locating the position of the new transect on the pre-project map. Then bed elevations were estimated by interpolating between the 1-ft contour lines and using nearby measured values at each location measured during the post-project survey.

All elevations measured under pre-project and post-project conditions were adjusted to correspond to the height of the measurements of the backsights recorded in December 1999. Therefore, the bed and water surface elevations of the transects presented graphically in Appendix 4 match those in the contour maps in Appendix 3.

SUBSTRATE PERMEABILITY

Substrate permeability, which was measured at the study sites during 4 surveys between 27 October 1999 and 5 July 2000, depends on the composition and degree of packing of the gravel and the viscosity of the water (as related to water temperature) and reflects “the ease with which water can pass through it” (Pollard 1955). Measurements were made with standpipes that were similar to the Terhune Mark IV permeability standpipe (Terhune 1958). Two standpipes were constructed for these measurements, one 4.5 feet long and the other 5.5 feet long. They were made of 1.12-inch (28 mm) inside diameter schedule-40 stainless steel pipe with a 3-inch long solid stainless steel driving tip at one end. Above the driving tip, there was a three-inch long cavity to store sand that entered the pipe during sampling. Immediately above the cavity, there was a three-inch long band of perforations around the standpipe. The perforations were 0.12 inch (3-mm) diameter holes, spaced 0.75 inches apart in columns of four holes. A 0.08-inch (2-mm) wide groove was cut about 0.08 inches deep along each of the columns to prevent sand grains from plugging the holes. There was a total of 12 rows of holes and every other column was offset by 0.375 inches to stagger the holes. A one-inch thick driving head was inserted into the standpipe when driving it into the streambed. The standpipe was marked with a band of red plastic tape 19.5 inches from the driving tip so that when the standpipe was driven into streambed to the red tape, the middle of the band of perforations was 12 inches below the surface of the substrate.

Permeability measurements were made with a homemade pumping device that employed a 12-volt DC battery and a 35 psi diaphragm vacuum pump (Thomas, model #107CDC20-975C) to draw water into a clear cylindrical vacuum chamber, 3.56 inches in diameter and 20 inches long. The device was mounted on a backpack frame. Two 3/8-inch polypropylene hoses were used, one to connect the pump to the vacuum chamber and the other to draw water from the standpipe

into the vacuum chamber. A 1/4-inch inside diameter plastic tube and a fiberglass tape with gradations in centimeters was attached to the side of the vacuum chamber to measure the change in height (i.e., volume) of the water drawn into the vacuum chamber. For each one-centimeter change in water height in the chamber, 64.7 ml were drawn into the chamber.

Two different methods were used to measure permeability, the first method was used for the 3 surveys between 27 October 1999 and 9 February 2000 and the second method was used for the fourth survey between 28 June and 5 July 2000. For both methods, the pump was switched on, and the hose was slowly lowered into the standpipe until a slurping noise was heard indicating that there was contact with the water. A one-inch spacer was then placed on top of the standpipe and a clamp was attached immediately above the spacer to the side of the hose without constricting it. The pump was then switched off, the spacer removed, and the hose lowered until the clamp rested on top of the standpipe. This placed the end of the hose one inch below the water's surface in the standpipe. The following describes the next steps for each of the two methods.

- For the first method, the pump and a hand-held water-resistant stopwatch (Sper Scientific) were then switched on simultaneously until about 1,300 ml of water were collected in the vacuum chamber. Smaller volumes were collected at sites with very slow pumping rates. In those cases, pumping occurred for at least one minute. At the end of pumping, the stopwatch was turned off at the same time the hose was lifted from the standpipe. Then, pumping was continued until all of the water in the hose had passed into the vacuum chamber. The volume pumped was measured to within 30 ml and the duration to pump the measured volume was measured to within 0.01 seconds. To compute the inflow rate using this method, it was necessary to correct the volume and duration of pumping to account for the initial 1 inch of water collected and the time required to collect it. The volume of the initial inch of water, which is 15.64 ml for the 1.12-inch pipe, was subtracted from the measured volume, and the time taken to remove it from the standpipe, estimated at 0.1 seconds, was subtracted from the measured time (Barnard and McBain 1994). Barnard and McBain (1994) recommended subtracting 0.25 seconds for the time required to pump 29.0 ml, which was the volume of the initial 1 inch of water from a 1.5 inch diameter standpipe with a hand-operated pump.
- For the second method, the pump was switched on and then after the water level in the vacuum chamber reached the zero mark, the stopwatch was activated. Usually after 1,294 ml had been collected, the stopwatch was turned off and the duration was recorded. When pumping rates were extremely slow, pumping was continued for at least 40 seconds and then the volume of water pumped and the exact duration were recorded. This method avoided the need to correct the duration and volume for pumping the initial 1 inch of water, which presumably resulted in slightly more accurate estimates.

Water temperature was also measured for both methods with an Extech electronic thermometer to the nearest 0.1°C to determine a viscosity correction factor.

The sample permeability was then interpolated from an empirical permeability versus a corrected inflow rate calibration table provided by McBain and Trush (Table 2 in Appendix 2). The calibration table provides conversions up to 110.9 ml/sec for field inflow rates whereas higher rates were measured at the restoration sites and in redds. Conversions were made for readings that exceeded 110.9 ml/sec by increasing the permeability by 500 cm/hr for each 0.1 ml/sec

increase in the field inflow rate beyond 110.9 ml/sec. For example, a field inflow rate of 111.0 ml/sec was converted to a permeability of 105,000 cm/hr. After the field inflow rates were converted to a permeability value, the permeability value was standardized to a temperature of 10°C by the viscosity correction factor presented in Barnard and McBain (1994).

The expected survival of chinook salmon eggs was computed using the results of McCuddin's study (1977) which tested the relationship between permeability and the survival to emergence of chinook salmon eggs in laboratory streams. However, these estimates should be viewed with caution as McCuddin simultaneously varied the sand concentration, permeability, and intragravel velocity for each test and so it is not possible to determine whether permeability or the other two factors affected egg survival. A linear regression was tested between the natural log of the permeability of three gravel mixtures with percentages of sediment less than 6.4 mm of 21%, 28%, and 39% and the survival to emergence (STE) of newly fertilized eggs during the first year of study (Figure 4). McCuddin's results for gravel mixtures with the highest permeability levels were not used in this regression analysis because the permeability did not appear to be accurately measured for his mixture with no fines and the STE for the mixture with 15% fines was not significantly different from STE for the mixture with 21% fines. McCuddin's results for his second year of study were not used because he reported that over time, the fine sediments settled in his experiment stream troughs creating a heterogeneous gravel mixture that greatly increased the variability among replicates. The adjusted- R^2 for the model of the limited data set between the log of permeability and percent survival of salmon eggs was 0.808. The expected survival of salmon eggs was computed using the following regression model:

$$\text{Percent Survival} = 0.1865 * \ln (\text{Permeability cm/hr}) - 1.0951$$

Permeability estimates that resulted in negative values were truncated at zero and high values were truncated at 77% for natural gravel mixtures and 88% for restoration gravel mixtures. The maximum STE of 77% for natural gravel mixtures is the average for McCuddin's first year tests with gravel mixtures of 16% and 21% fines. The maximum STE of 88% for restoration gravel mixtures is the average for McCuddin's gravel mixtures with no fines less than 6.4 mm (0.25 inch), which corresponds to the KFGRP and DFG restoration gravel mixtures.

PIEZOMETER DESIGN

Intragravel water samples were collected from piezometers buried in artificial redds, approximately 12 inches below the substrate's surface. Four piezometers were installed at each of the 26 study riffles as shown in the contour maps in Appendix 3 between 18 and 23 October 1999.

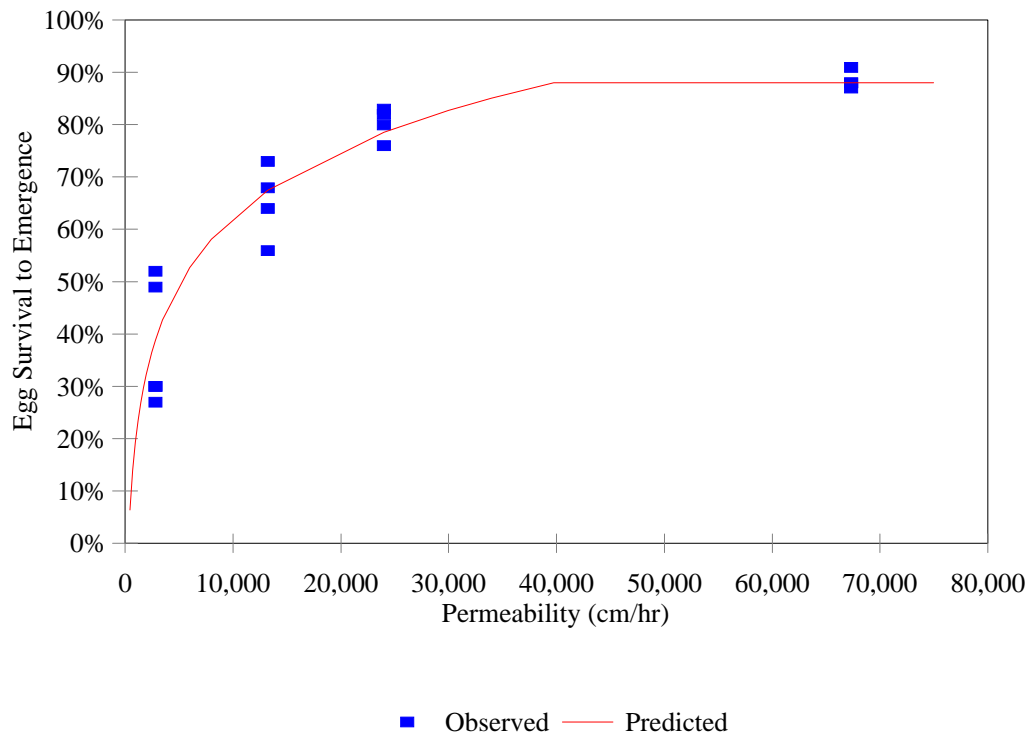


Figure 4. Survival to emergence of chinook salmon eggs relative to gravel permeability based on first-year data from a laboratory stream study by McCuddin (1977). The observed survival to emergence estimates at 67,350 cm/hr correspond to McCuddin's tests with no fine sediment less than 6.4 mm. The solid line indicates the predicted survival to emergence for restoration gravel mixtures based on the equation shown above with the estimates truncated at 88%..

Piezometers were 10-inch long, 1/4-inch outside diameter copper tubes, each with one end of the tube pinched nearly closed and eight 0.04-inch diameter holes drilled or punched in the tube near the closed end. The middle of the copper tube was positioned in the center of a 4-inch x 4-inch x 4-inch cement cube that was allowed to harden around the tube to serve as an anchor. A latex additive was added to the cement to maintain its integrity in water. The other end of the copper tubing was attached to a clear polyvinyl chloride (PVC) flexible tube that extended to the surface of the water. The PVC tubing was 1/4-inch inside diameter and had a wall thickness of 1/16-inch.

A 1.25-inch inside diameter PVC pipe was embedded in the piezometer's cement anchor to contain an *Onset StowAway TidbiT* thermograph. The PVC pipe extended 3 to 4 inches from the cement anchor and the thermograph was suspended within the center of the pipe with 15-pound test monofilament line. A PVC cap was placed over the open end of the pipe and twelve 5/16-inch holes were drilled into the pipe and three more holes were drilled into the cap.

Piezometers were installed to simulate sampling in an egg pocket in a natural salmon redd. Pits were dug approximately 12-inches deep by 12-inches wide at the bottom with a hand-held hoe. The excavated substrate was piled downstream of the pit to simulate the tailspill formed in a natural redd. After the piezometer was placed in the pit, sediment was pulled into the pit in thin

layers from the upstream areas using the hoe. The blade of the hoe was then fanned over each layer of gravel in the pit to flush most of the fines onto the tailspill. When completed, the piezometer was located at the upstream end of the tailspill which was raised several inches above the undisturbed streambed. An egg pocket would be expected to occur in this location in a natural redd (Vronskiy 1972, Hawke 1978). Immediately upstream of the tailspill, there was a two- to four-inch deep depression in the streambed that simulated the pit of a small, but natural-looking redd. At some of the artificial redds, the depressions were filled and the tailspill eroded away by natural sediment transport within seven to ten days. This smoothing also occurs at natural redds (Vronskiy 1972, Mesick 2001a).

INTRAGRAVEL DISSOLVED OXYGEN CONCENTRATION

One intragravel D.O. sample was collected from each of the 104 piezometers during eight surveys between 18 October and 28 December 1999 and during three more surveys between 26 January and 5 July 2000. Samples were collected using a 50-ml polypropylene, disposable syringe (Henke-Sass Wolf GmbH, Germany) fitted with a six-inch long, 1/8-inch inside diameter polypropylene tube and a tapered connector that provided an airtight seal between the piezometer's tubing and the syringe's tubing. Water samples were collected by first slowly withdrawing and discarding 50-ml of water, the approximate volume of water in the piezometer's tubing, and then using it to rinse the sample bottle. Then a 60-ml sample was slowly withdrawn and injected into a LaMotte sample bottle. A LaMotte test kit, model EDO/AG-30 was used for the analysis. The LaMotte test uses the azide modification of the Winkler Method and a LaMotte Direct Reading Titrator for the final titration. The kit measures D.O. concentration in 0.1 parts per million (ppm) increments. Kit reagents were replaced for each survey. Immediately after the samples were collected at a site, they were fixed and placed in an ice chest. They were analyzed at room temperature within 10 hours after collection.

A surface D.O. sample was collected at each site at the same time the intragravel samples were collected. The percent saturation of dissolved oxygen for the intragravel samples was computed by dividing the D.O. concentration of the intragravel sample by the D.O. concentration of the surface sample.

INTRAGRAVEL WATER TEMPERATURE

Intragravel and surface water temperatures were measured to provide an index of downwelling of surface flow. High D.O. levels and presumably high downwelling rates corresponded to piezometer sites where the magnitude and fluctuation of intragravel water temperatures matched those in surface water temperatures in the Stanislaus River in fall 1996 (CMC 1997). Conversely, low D.O. levels and presumably low downwelling rates corresponded to sites where intragravel water temperatures were relatively high and stable (CMC 1997).

An *Onset StowAway TidbiT* thermograph was buried with each piezometer inside perforated PVC pipe to record intragravel water temperatures at 30-minute intervals. Thermographs were also installed in perforated PVC pipes chained near the stream margin to record surface water temperatures at riffles DFG2, TMA, R5, R10, R14, R19, R28A, R43, R59, and R76.

Comparisons between surface and intragravel measurements at riffles where no surface thermograph was installed utilized the surface data collected at the closest riffle. Measurements began on 18 October 1999 at 8:00 a.m. prior to the installation of the piezometers and ceased when the piezometers were removed between 6 February and 5 July 2000.

VERTICAL HYDRAULIC GRADIENT

The ratio of the differential head to the depth of the piezometer below the sediment-water interface (Lee and Cherry 1978; Dahm and Valett 1996) is known as the vertical hydraulic gradient (VHG). Negative VHG measurements indicate the downwelling of surface flow and positive values indicate the upwelling of intragravel flow. VHG was measured at the piezometers during each survey. The differential head was measured with a manometer consisting of a 9-ft long, 1/4-inch inside-diameter, clear PVC tube. One end of the tube of the manometer was connected to the piezometer's tubing with an air tight connector and the other end of the tube was attached to a wooden stake that was held near the substrate's surface (Lee and Cherry 1978; Dahm and Valett 1996). A silicone pipet bulb with emptying and filling valves was attached to the middle of the tubing with a t-connector to facilitate filling the manometer with water. Measurements were made by partially filling the manometer's tubing with water and then holding the middle of the tube at eye level to form a loop with two vertical tubes and a single air bubble at the top of the loop. Before the measurement was made, the manometer was inspected to ensure that there were no air bubbles trapped in the water columns or fine sediment/debris blocking flow through the tubes. The differential head was read as the difference in height in centimeters between the water levels in the two tubes. Measurements were recorded as negative when the water level in the side of the tube connected to the piezometer was lower than the level in the side of the tube held at the substrate's surface. VHG is computed as the differential head divided by 30 cm, which is the approximate difference in elevation between the holes in the copper tubing of the piezometer and the substrate's surface.

STATISTICAL ANALYSES

All statistical analyses, including *t*-tests, *F*-tests, correlations, and regressions, were made using the Statistix Version 7.0 software program (Analytical Software 2000). Scatter plots with means and error bars were generated with SigmaPlot for Windows Version 7.0.

RESULTS

The Department of Fish and Game's preliminary estimate of chinook salmon escapement (grilse and adults) to the Stanislaus River in fall 1999 is 4,500 fish (Robert Kano, 3 January 2002). During the fall 1998 pre-project surveys, the preliminary escapement estimate for the Stanislaus River is 3,147 fish.

DISTRIBUTION AND TIMING OF SPAWNING

A total of 703 redds was observed where gravel had been placed at the 18 KFRGP riffles and 711 redds were observed at the seven control sites and in natural gravel adjacent to the gravel placement areas between 19 October and 15 December 1999 (Table 3 in Appendix 2). Comparing the same locations surveyed in fall 1999 with those surveyed in fall 1998, the number of redds observed in natural gravel was about 1.7 times greater in 1999 than in 1998, whereas the number observed in the restoration gravel was about 3.7 times greater in 1999 than in 1998.

Spawning began in early October 1999 as numerous fish were observed constructing redds at Riffle TMA on 8 October. During the first survey between 19 and 23 October, a total of 230 redds was observed, which was 16% of the total. By 1 November, 29.7% of the total number of redds had been counted, which was slightly higher than occurred in fall 1998 when 25% of the redds had been counted by 1 November. Most of the spawning had been completed by mid December. During the sixth survey between 4 and 6 December, 68 new redds and 17 live adult fish were counted; whereas no additional redds or fish were observed after 15 December when the total station surveys were completed.

Chinook salmon spawned at all of the project sites, except for Riffle R78, which was the downstream most site near Oakdale (Table 3 in Appendix 2). As occurred in fall 1998 (CMC 2001), redd densities were highest at the upstream sites and they gradually declined in a downstream direction (Figure 5). There were strong negative correlations between redd densities and the distance downstream from Goodwin Dam for two restoration gravel mixtures and the control sites. However, the correlation for the project sites that received the gravel mixture of Stanislaus River rock cleaned with a 3/8 inch screen was not significant. The following table presents the coefficient and constant for the variable for the distance downstream from Goodwin Dam, the total degrees of freedom (*df*), the probability level (*P*) for the regression, and the adjusted- R^2 for linear regressions between the density of redds and the distance downstream from Goodwin Dam for each gravel mixture.

Gravel Mixture	Coefficient	Constant	<i>df</i>	<i>P</i>	adj- R^2
Stanislaus rock 1/4-inch screen	-0.0348	0.4734	5	0.0152	0.757
Stanislaus rock 3/8-inch screen	-0.0217	0.3493	5	0.1106	0.388
Tuolumne rock 3/8-inch screen	-0.0119	0.1961	5	0.0559	0.550
Control Sites	-0.0165	0.2881	6	0.0056	0.774

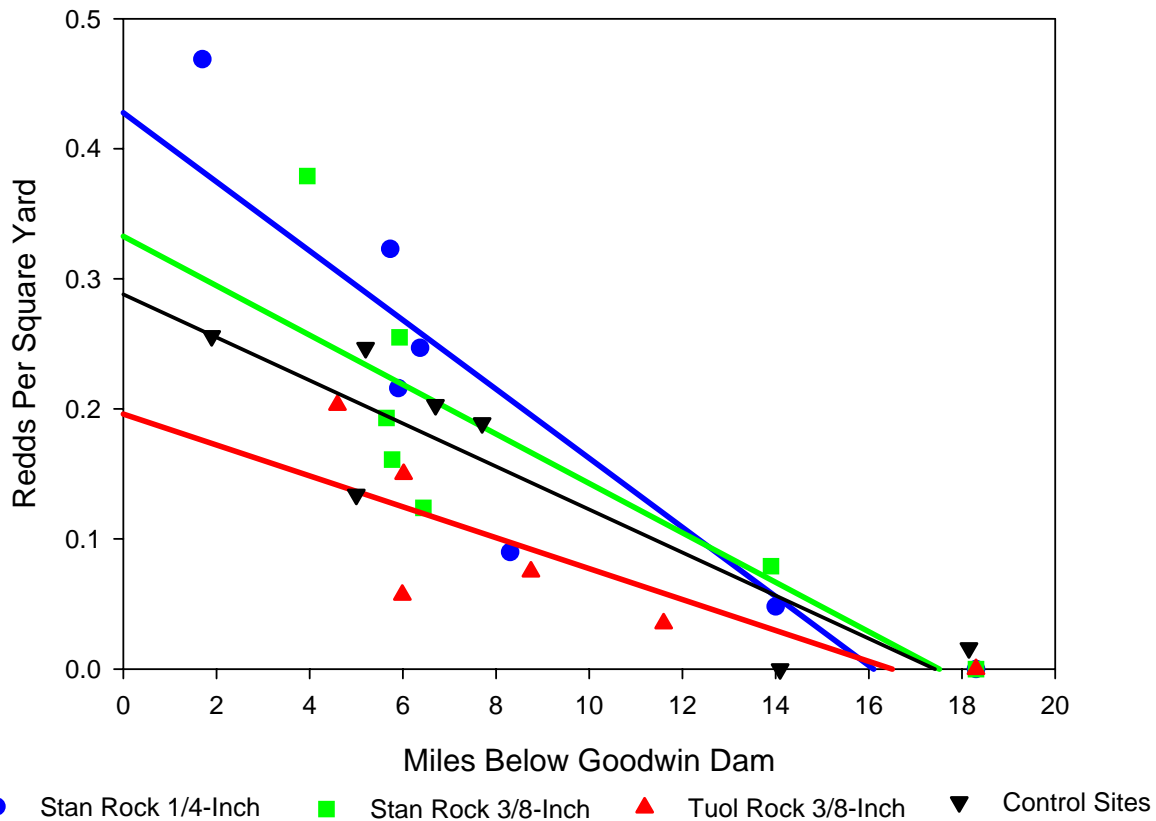


Figure 5. Chinook salmon redd densities at project sites that received three different mixtures of gravel: (1) Stanislaus River rock cleaned with a 1/4-inch screen, (2) Stanislaus River rock cleaned with a 3/8-inch screen, and (3) Tuolumne River rock cleaned with a 3/8-inch screen and the control sites relative to the distance below Goodwin Dam in the Stanislaus River in fall 1999. Regression models are shown as lines. The models for both sizes of Stanislaus River rock assume that at sites 18 miles below Goodwin Dam, redd densities would have been near zero and similar to the densities observed for the Tuolumne River rock and Control sites.

A total of 90 redds was observed in fall 1999 at the DFG restoration site in upper Goodwin Canyon, referred to as DFG2 in this report. The gravel was placed at a site that was approximately 80 feet wide by 60 feet long in 1997. By fall 1998, some of the gravel in the center of the riffle had been flushed away by high flows and there were about 144 square yards of spawning habitat in fall 1999. The density of redds at DFG2 was 0.625 per square-yard, which was higher than the densities observed at any of the KFGRP sites. Presumably, high redd densities occurred at DFG2 because it was the upstream most site surveyed and there were few nearby riffles suitable for spawning.

EFFECTS OF GRAVEL SOURCE AND SIZE ON REDD DENSITY

The evaluation of hypotheses III-A, III-B, and III-C regarding spawner utilization of different sources and size distributions of restoration gravel (see the Introduction for details on the hypotheses) had to consider the negative correlation between redd density and the distance downstream from Goodwin Dam. One means of avoiding this location effect was to compare the redd distribution on contour maps between pre-project and post-project surveys at the same site (Appendix 3). These maps clearly indicate that numerous salmon spawned where both

Stanislaus River rock and Tuolumne River rock had been placed in fall 1999 where no salmon spawned in fall 1998 under pre-project conditions. This indicates that salmon will spawn at restoration sites shaped like the tail of a pool within one month of construction. However, salmon avoided some of the areas where Tuolumne River rock had been placed in deep layers and instead spawned in shallow layers of Tuolumne River rock or in nearby natural gravel that was relatively silty and compacted. This was particularly evident at three of the six riffles, R15, R29, and R43, where few salmon spawned and a deep layer of Tuolumne River rock was placed. Salmon spawned at two other sites that received Tuolumne River rock, including Riffle R5 which was located in a preferred upstream spawning area with no other nearby riffles and at R16 where the gravel was placed in a relatively thin layer. No salmon spawned at Riffle R78, which also received Tuolumne River rock; however it was the downstream most site and few fish spawned at the nearby riffles in fall 1999. Statistical tests of pre- and post-project redd densities would not be meaningful because the escapement was considerably different between the surveys.

The hypotheses were also tested with two-tailed *F*-tests that compared the residual variances, slopes, and elevations of the regressions of redd density versus distance downstream between the different gravel mixtures shown in Figure 5 (Snedecor and Cochran 1989, pages 390-393). Before the tests were conducted, the regressions for both sizes of Stanislaus River rock were recomputed based on the assumption that redd densities would have been near zero approximately 18 miles below Goodwin Dam as occurred with the Tuolumne River rock and control sites. Otherwise, the unadjusted regressions for the Stanislaus River rock sites would suggest that salmon spawn further downstream in the control sites and Tuolumne River rock sites than in the relatively well used Stanislaus River rock sites. Furthermore, comparisons of the unadjusted regressions might have falsely suggested that the regression slopes for the Stanislaus River rock sites were significantly higher than those for the Tuolumne River rock and control sites. To compare the regressions, the *F*-test requires that the variance of the regressions is not significantly different before testing the slope and elevation of the regressions. As there were no significant differences between the variances of the adjusted regressions, it was possible to compare the slopes and/or elevations of all possible comparisons (Table 4 in Appendix 2). The results of the *F*-tests are summarized below.

- The elevation of the regression for the sites with Stanislaus River rock cleaned with a 1/4-inch screen was significantly greater ($P = 0.039$) than for the regression with the Tuolumne River rock sites. Therefore, redd densities at the sites with Stanislaus River rock cleaned with the 1/4-inch screen were greater than at the sites with Tuolumne River rock.
- The elevation of the regression for the sites with Stanislaus River rock cleaned with a 3/8-inch screen may have been significantly greater ($P = 0.073$) than for the regression with the Tuolumne River rock sites. Therefore, redd densities at the Stanislaus River rock sites were possibly greater than the densities at the sites with Tuolumne River rock.
- The elevation of the regression for the control sites may have been significantly greater ($P = 0.096$) than for the regression with the Tuolumne River rock sites. Therefore, redd densities at the control sites were possibly greater than the densities at the sites with Tuolumne River rock.
- None of the other comparisons of slopes or elevations for the regressions were statistically significant ($P \geq 0.167$). Although the slope of the regression for the sites

with Stanislaus River rock cleaned with a 1/4-inch screen was 61% higher than the slope for the regression for the control sites, the difference was not significant ($P = 0.167$)

STREAMBED ELEVATION

The pre-project streambed elevation profiles measured between 4 and 20 August 1999 and the post-project elevation profiles measured between 24 August and 29 September 1999 are shown in Appendix 4. They are provided as baseline information to be used in future analyses of sediment transport. The post-project elevations shown in these comparisons were not subjected to high flows nor spawning salmon. The water surface elevations shown were measured in December 1999 and reflect spawning conditions. The widening of the channel that occurred at riffles TMA, R29, and R43 was a direct result of construction. The pre-project profile for Riffle R43 shows one of the four concrete slabs from an old flood damaged bridge that were removed from the streambed during construction.

SUBSTRATE PERMEABILITY

The initial permeability rates measured between 27 October and 1 November 1999 at a depth of 12 inches were significantly greater at the restoration sites, particularly those that received the Tuolumne River rock, than at the control sites (Table 5 in Appendix 2). Measurements taken in areas where the restoration gravel was at least 18 inches deep averaged 204,827 cm/hr ($n = 6$) for the Tuolumne River rock cleaned with a 3/8-inch screen, 171,436 cm/hr ($n = 20$) for the Stanislaus River rock cleaned with a 3/8-inch screen, and 150,990 cm/hr ($n = 8$) for the Stanislaus River rock cleaned with a 1/4-inch screen. In comparison, mean permeability was 3,477 cm/hr ($n = 21$) at the six control riffles with natural gravel during October and November 1999 and 3,129 cm/hr at all 25 sites prior to gravel addition in August 1999 (CMC 2001). The differences were significant between the Tuolumne River rock and the 1/4-inch Stanislaus River rock ($P = 0.02$) and all three types of restoration rock and the control sites ($P = 0.00$) based on two-sample t-tests. However, the differences between the Tuolumne River rock and the 3/8-inch Stanislaus River rock, ($P = 0.09$) and the two sizes of Stanislaus River rock ($P = 0.25$) were not significantly different.

At the sites where the restoration gravel was placed in a 12-inch or shallower layer, the permeability rate was quite variable depending on whether the restoration gravel was deeper or shallower than the holes in the standpipe during sampling (Table 5 in Appendix 2). Where restoration gravel was approximately 12 inches deep, the mean permeability was 101,656 cm/hr and the range was 747 to 222,038 cm/hr ($n = 15$) during the first survey in late October and early November. In contrast, the mean permeability was 24,200 cm/hr and the range was 649 to 161,210 cm/hr ($n = 11$) during the first survey where the restoration gravel was six to 12 inches deep. The permeability rates at these sites tended to decline after spawning began presumably because redd construction mixed the restoration gravel with the silty, natural gravel. By mid-December 1999 when spawning was almost completed, the mean permeability was 35,279 cm/hr at sites where restoration gravel was approximately 12 inches deep, 32,419 cm/hr where restoration gravel was six to 12 inches deep, and 7,076 cm/hr at the control sites. The difference

was significant ($P = 0.03$) between the 12-inch deep sites and the control sites but not between the six to 12-inch deep sites and the control sites ($P = 0.22$) based on two-sample t -tests.

Permeabilities declined following turbid storm runoff on 25 January 2000 that left a thick blanket of fines covering all riffles, particularly at Riffle R43 and those downstream of the Orange Blossom Bridge. At 34 sites where permeability was measured in both mid December 1999 and early February 2000 (Table 5 in Appendix 2), the mean permeability significantly declined ($P = 0.00$) from 125,485 cm/hr in mid December to 35,615 cm/hr in early February based on a paired t -test (Figure 6). Sharp declines in permeability occurred at all restoration sites, even those with no accumulation of fines on the riffle's surface.

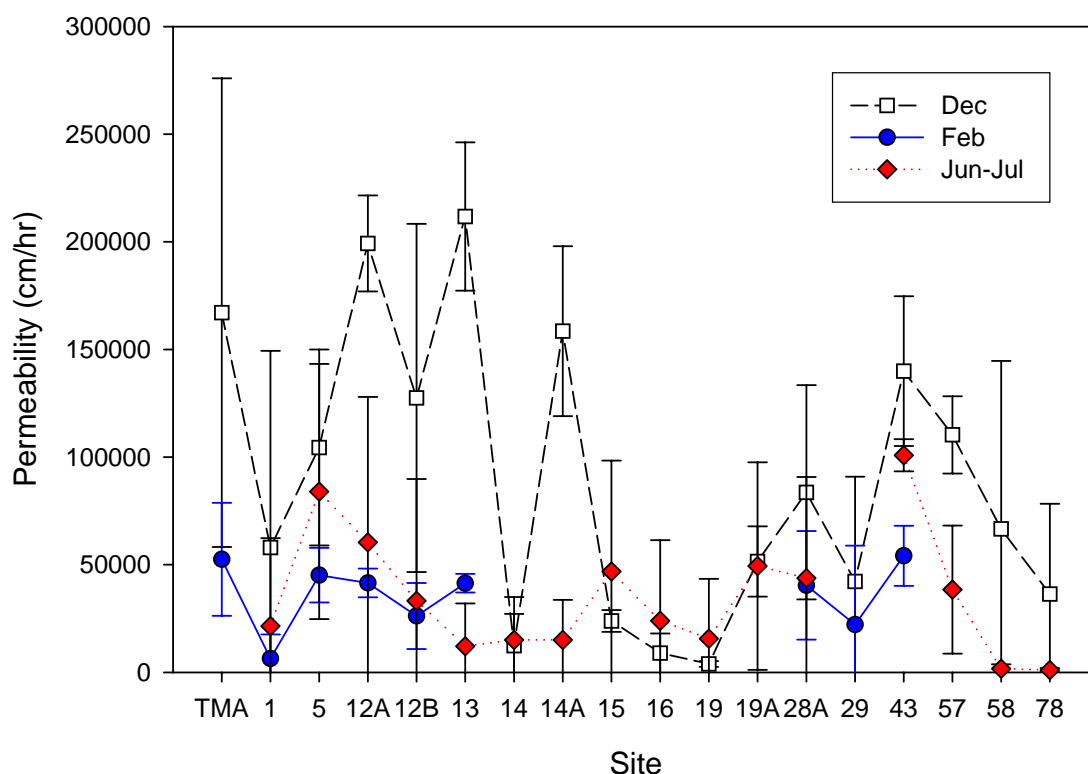


Figure 6. Scatter plot showing the mean permeability and standard deviation (error bars) at a depth of 12 inches in undisturbed gravel within project sites in the Stanislaus River between 14 and 19 December 1999 (Dec), 6 and 9 February 2000 (Feb), and 27 June and 5 July 2000 (Jun-Jul). Sites are arranged along the x-axis from the upstream most site (TMA) to the downstream most site (R78).

After 53 days of clean reservoir releases of about 1,500 cfs between 20 April and 12 June 2000, permeabilities increased at most sites (Figure 6) but declined at the upstream half of riffles R12A, R12B and R13 which are near Lover's Leap (Table 5 in Appendix 2). The mean permeabilities significantly ($P = 0.007$) increased at riffles R1, R5, and R43 and the downstream piezometer sites at riffles R12A and R12B from 32,950 cm/hr in February to 70,636 cm/hr in June and July 2000 based on a paired t -test. Conversely, the mean permeabilities significantly (P

= 0.002) decreased at Riffle R13 and the upstream piezometer sites at riffles R12A and R12B from 36,212 cm/hr in February to 8,270 in June 2000 based on a paired *t*-test. These results suggest that while high reservoir releases help flush relatively small suspended sediments from the restoration riffles that were deposited during the January 2000 rain storm, these flows also mobilize and deposit larger fines (<2 mm) in restoration riffles that were stored in the mined channels near Lovers Leap.

Immediately following an intense rain storm on 7-8 November 1999 that increased flows by about 15 cfs but did not substantially increase turbidity, a thick blanket of fines was deposited only at Riffles R15 and R16. These riffles are adjacent to the washing pond of Ohe Sand and Gravel, which is an active gravel mine. The bed permeability at Riffle R15 declined from a mean of 220,898 cm/hr on 30 October to a mean of 23,875 cm/hr on 16 December 1999 probably as a result of the early November rain storm. Presumably sand-laden water from the washing pond overflowed into the river during that storm. It is also likely that the mined channel in the Lovers Leap reach (R12 to R20) contains high concentrations of fines from relatively recent mining activities. Furthermore, the placement of gravel to restore spawning habitat may have accelerated the movement of these fines.

The estimated survival rate of chinook salmon eggs to emergence based on bed permeabilities was high at most of the restoration sites, particularly those where the layer of new gravel was at least 18 inches deep (Table 5 in Appendix 2). Through early February 2000, survival to emergence was estimated to near the maximum rate ($\geq 80\%$) at two-thirds (25/38) of the piezometer sites in restoration riffles measured in February. The average estimate survival rate was 44% (range 0 to 78%) for the other 13 sites in restoration riffles measured in February. It is not possible to compare survival rates between restoration and control sites using the fall 1999 data, because permeability measurements must be made within redds and not within undisturbed gravel as was done here. The female chinook salmon greatly increases the permeability of the gravel during the construction of her redd. Permeability was measured at five redds constructed at control riffles R10, R12, and R19 in December 1999. The mean permeability for these five redds is 143,322 cm/hr (range of 38,512 to 204,000 cm/hr), which corresponds to the maximum survival rate of 77% for all six redds. However, four of these redds were constructed shortly prior to the permeability measurement and it is likely that redd superimposition and the intrusion of fine sediments from turbid storm runoff would reduce both permeabilities and egg survival. A comparison of permeability within salmon redds between restoration and control sites will be made using fall 2000 data that will be presented in the Task 6 report.

INTRAGRAVEL DISSOLVED OXYGEN CONCENTRATION

The intragravel D.O. concentrations were relatively stable during all surveys and unaffected by several intensive rain storms that occurred in late January and early February 2000 (Table 6 in Appendix 2). The mean D.O. concentration at the restoration sites in December, which is 92.8% of saturation, is not significantly different ($P = 0.12$) from the concentration of 94.5% of saturation that was observed in early February. Similarly, the mean D.O. concentration at the control sites in December, which is 79.2% of saturation, is not significantly different ($P = 0.20$) from the concentration observed in early February, which is 84.6% of saturation. This suggests that the turbid runoff that occurred in January and February 2000 had no effect on intragravel

D.O. concentrations unlike the substantial decline that was observed after intensive rainstorms in January and February 1996 (Mesick 2001a).

Intragravel D.O. concentrations were higher and more suitable for hatching at the restoration sites than at the control sites during mid-December, when chinook salmon eggs begin to hatch and their oxygen requirements are highest (Figure 7). During the mid-December survey, D.O. concentrations were greater than 8.0 ppm, which is probably adequate for 100% survival to hatching (see the chapter “Literature Review of Salmonid Egg Survival”), at 98.5% of the 68 piezometers in the restoration sites but greater than 8.0 ppm at only 77.8% of the 27 piezometers in the control sites (Table 6 in Appendix 2). The mean D.O. concentration at 68 piezometers at the restoration sites was 10.7 ppm (92.9% saturation), which is significantly greater ($P = 0.000$) than the mean concentration at 27 piezometers at the control sites, which was 9.3 ppm (79.2% of saturation) based on a comparison of the percent saturation of the samples using a two-sample t-test.

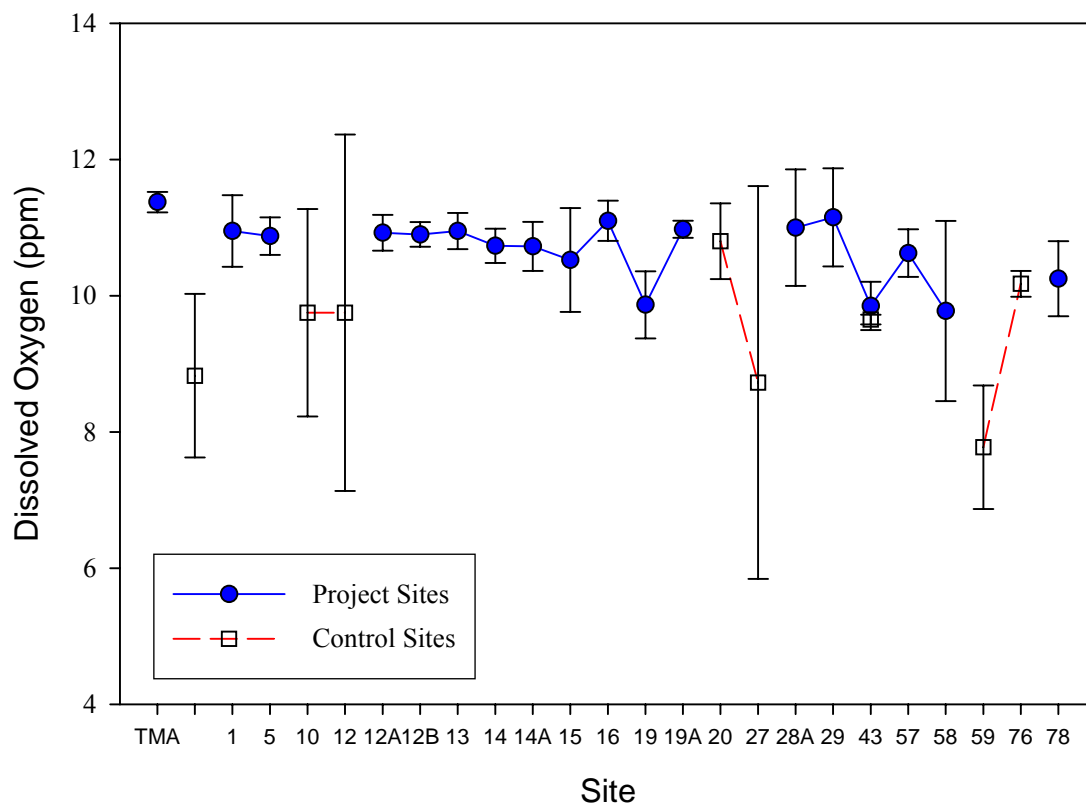


Figure 7. Scatter plot showing the mean intragravel dissolved oxygen concentration and standard deviation (error bars) in artificial redds in project and control sites in the Stanislaus River between 14 and 19 December 1999. Sites are arranged along the x-axis from the upstream most site (TMA) to the downstream most site (R78). Riffle TM1 is unlabelled and immediately downstream from Riffle TMA.

Another analysis was made for the early February survey, because it is the end of the sensitive period for egg survival as most of the chinook salmon eggs have hatched and it would show the effect of fine sediment intrusion from the intensive rain storms in late January and early February. During the February survey, D.O. concentrations were greater than 8.0 ppm at all 31 of the piezometers measured at the restoration sites and at 87.5% of the 16 piezometers measured at the control sites (Table 6 in Appendix 2). The mean D.O. concentration at the restoration sites was 11.1 ppm and 94.5% of saturation, which was significantly greater ($P = 0.009$) than the mean D.O. concentration at the control sites, which was 9.7 ppm and 84.6% of saturation based on a comparison of the percent saturation of the samples using a two-sample t-test.

VERTICAL HYDRAULIC GRADIENT

The vertical hydraulic gradient (VHG) was low at all sites in fall 1999 and there was no indication that the addition of clean gravel to the restoration sites affected upwelling or downwelling in the artificial redds with the piezometers (Table 7 in Appendix 2). The absolute value of the VHG was less than 0.066 at most piezometers, which indicates that the hydraulic head was usually 2 centimeters or less. Furthermore, the VHG routinely switched from positive readings, which indicate upwelling, to negative readings, which indicate downwelling, and vice versa at many of the piezometers. There were no consistent differences in VHG between the restoration sites and the control sites and there was no noticeable effect of turbid storm runoff on the measurements made in early February. These results suggest that the VHG is typically low in highly permeability gravel such as occurs in the artificial redds used in this study. The VHG measured in undisturbed gravel with standpipes in fall 1998 averaged 0.113 (CMC 2001), which is substantially higher than the typical maximum reading observed in fall 1999 in the artificial redds.

INTRAGRAVEL WATER TEMPERATURE

Intragravel and surface water temperatures were measured to provide an index of downwelling rates of surface flow. Presumably if downwelling rates are high, then the magnitude and fluctuation of the intragravel water temperatures should be nearly identical to those of the surface. The only normal difference between surface and intragravel temperatures in highly permeable gravel is that intragravel water temperatures tend to lag behind surface temperatures by one to two hours. In contrast, when fine sediments accumulate in redds, downwelling rates would be reduced and the proportion of groundwater that upwells into a redd would increase. If the rate of groundwater upwelling is substantial, then the intragravel water temperatures would be relatively high and stable compared to surface temperatures. Groundwater upwelling in the redd would also result in low D.O. levels (McNeil 1969, Leitritz and Lewis 1980). A previous study in the Stanislaus River in fall 1995 indicates that groundwater upwelling increased and D.O. levels substantially declined immediately following flow fluctuations from storm runoff (Mesick 2001a). A subsequent study in the Stanislaus River in fall 1996 determined that low D.O. levels occurred at artificial redds where intragravel water temperatures were relatively high and stable prior to any flow fluctuations (CMC 1997). The purpose of using an index based on differences in intragravel and surface water temperatures is to determine the timing and magnitude of groundwater upwelling. Knowledge of the timing and magnitude of groundwater

upwelling should help determine the effects of various sources of fine sediment such as redd superimposition, turbid storm runoff, and high flow releases from New Melones Reservoir on intragravel water conditions in restoration gravel versus natural gravel.

Of the 103 thermographs installed with the piezometers, only 92 were recovered. Of the 26 thermographs installed in natural gravel at riffles TM1, R10, R12, R20, R43, R59, and R76, 24 thermographs were recovered; piezometers P3 and P4 at Riffle R43 were installed in natural gravel. Of the 70 thermographs installed in restoration gravel at the eighteen project riffles, 62 were recovered; piezometers P1 and P2 at Riffle R43 were installed in restoration gravel. Of the seven thermographs installed at the CDF&G restoration sites, riffles DFG2 and R27, six were recovered. Most of the piezometers were lost as a result of redd superimposition, although vandalism was suspected at some sites. Eight of the fall 1999 piezometers and thermographs were recovered during fall 2000 surveys after spawning salmon uncovered them during redd construction.

The magnitude and fluctuation in intragravel water temperatures were nearly identical to those of the surface water at 85% (78/92) of the piezometer sites from the time they were buried between 18 and 23 October until early February when some were retrieved or until 10 March for others. As examples of these sites, the data from the surface thermographs and the thermographs buried at piezometers DFG2 P1, TMA P1, R12 P1, R15 P1, R28A P2, R43 P1, R57 P2, and R78 P2 are plotted in Appendix 5. Minor differences between the two sets of measurements should not be considered to be significant because the *StowAway TidbiT* has a temperature accuracy of ± 0.36 degrees Fahrenheit and an error in the time function that is as much as one hour per year (Onset 1998).

Intragravel D.O. levels were usually below 8.0 ppm and bed permeabilities were low at artificial redds where intragravel water temperatures were relatively stable and at least 1.0 degree Fahrenheit higher than surface water temperatures (Table 8 in Appendix 2). The most extreme deviations occurred at R58 P4, which is a restoration site where intragravel temperatures were relatively stable and elevated by as much as 6 degrees Fahrenheit, and at R59 P3, a natural gravel site where intragravel temperatures were stable and elevated by as much as 13 degrees Fahrenheit. Other sites where intragravel water temperatures were stabilized and elevated by at least 1.0 degree Fahrenheit include piezometers R10 P4, R12 P2, and R59 P2. Intragravel D.O. concentrations were also less than 8.0 ppm at these sites. The intragravel water temperature was elevated by about 0.8 degrees Fahrenheit at R59 P1, where intragravel D.O. concentrations averaged 8.0 ppm (range 7.0 to 8.5 ppm) between 5 November 1999 and 9 February 2000.

Artificial redds where intragravel water temperatures were either stabilized slightly or elevated by 0.5 degrees Fahrenheit or less during November and December 1999 include piezometers TM1 P4, R10 P1, R10 P2, R10 P3, R10 P4, R12 P3, R43 P4, R59 P1, R59 P4, R78 P1, and R78 P3. Intragravel D.O. concentrations at these sites usually exceeded the mean for all sites and so these temperature deviations probably do not represent significant upwelling rates of oxygen-poor groundwater.

These results suggest that elevations in intragravel water temperatures by 0.8 degrees Fahrenheit or more are an indication of high rates of upwelling of oxygen-poor groundwater that are sufficient to reduce egg survival or impair alevin health. Intragravel water temperatures that

were elevated by at least 0.8 degrees Fahrenheit occurred at 20.8% (5/24) of the artificial redds in the control sites and at 1.6% (1/62) of the artificial redds in the project sites. The only site where elevated temperatures occurred in a project riffle, R58 P4, was where the gravel was placed in a 6-12 inch deep layer. Therefore, even this artificial redd was created in a mixture of natural and restoration gravel.

It is likely that elevations in intragravel water temperatures that occurred in October and November 1999 were a result of fine sediment intrusion that resulted from the intragravel transport of fines in silty riffles during normal flow releases. Intragravel water temperatures were similar to the surface water temperatures at all but two artificial redds during at least the first few days. This indicates that the artificial redds were constructed such that permeabilities and the downwelling of surface flow were initially adequate. Intragravel water temperatures were high and relatively stable immediately after constructing the artificial redds at R10 P2 and R12 P2 which suggests that these sites may not have been adequately cleaned during redd construction or the rate of groundwater upwelling was unusually high. The elevated intragravel water temperatures were not caused by the construction of nearby redds at many of the sites, such as Riffle R59, where no spawning occurred and intragravel water temperatures were elevated in November and December at three artificial redds. Furthermore, the substantial elevations in intragravel water temperatures (≥ 1 degree Fahrenheit) at six artificial redds occurred prior to the 8 November 1999 storm, which was the first storm after the piezometers were buried. Therefore by the process of elimination, fine sediment intrusion occurred at artificial redds after they were constructed presumably as a result of intragravel transport of fines in silty riffles during normal flow releases.

Intragravel water temperatures became elevated at 44% (19/43) of the artificial redds around 15 February 2000, which was one day after 1,500 cfs flood control releases were begun (Appendix 5). Monitoring was continued throughout the flood control releases until late June or early July at most of the riffles near Lovers Leap (R13-R20), Valley Oak Park (R57-R59), and Oakdale Recreational Park (R76 and R78). Elevations of at least 1 degree Fahrenheit occurred at R19 P4 and R58 P3 on 15 February that suggest that intragravel D.O. levels had declined to 8 ppm or less (Appendix 5). By late June and early July, the intragravel D.O. level had declined to 5.8 and 6.1 ppm, respectively, at these two piezometers.

Elevations of 0.5 degrees Fahrenheit or less and/or stabilized temperatures began on 15 February at piezometers R14 P1, R14 P3, R14A P1-P4, R16 P3, R19 P1, R19 P2, R57 P3, R58 P1, and R58 P2 (Appendix 5). Similar changes were observed in late January at R76 P4 and R78P2, which was immediately following the first intensive storm runoff, and at R76 P1, R76 P3, and R78 P4 in early February, which was after several storm events but prior to flood control releases (Appendix 5).

The water temperature patterns observed after 15 February generally continued until after the flow releases were reduced to 300-cfs on 21 June 2000 at the Valley Oak and Oakdale Recreational parks (Appendix 6). However, the elevations in intragravel temperatures ceased while the stabilizations continued after 21 June at piezometers R58 P3 and R58 P4 and the minor stabilization ceased at R57 P3 after 21 June (Appendix 6). Although it was not possible to evaluate whether the water temperatures were elevated relative to the surface temperatures at the Lovers Leap Reach after 31 March because the surface thermographs at riffles R14 and R27 had been retrieved, it was possible to determine that the pattern of daily fluctuations in the

intragravel water temperatures remained unchanged between 15 February and 23 June at the Lovers Leap riffles (Appendix 6).

At 15 piezometers where the intragravel water temperatures were elevated by no more than 0.5 degrees Fahrenheit and/or stabilization began between late January and 15 February, the mean intragravel D.O. concentration was 7.7 ppm (72.0% of saturation) in late June and early July. In contrast, the mean intragravel D.O. concentration was 9.3 ppm (84.4% of saturation) in late June and early July at 19 piezometers where no temperature deviations were observed. The difference in percent saturation between these two groups was statistically significant ($P = 0.000$) based on a two-sample t-test.

CONCLUSIONS

The initial post-project monitoring conducted in fall 1999 provided evidence for 8 of the 10 hypotheses identified in the Ecological Monitoring Plan (CMC 1999b). Evaluations of the hypotheses on the effects of site selection and project design on gravel transport and the useful life of the project will be evaluated in the Task 6 report. Other issues discussed include the need to directly measure egg survival to emergence and the utility of monitoring intragravel water temperatures to provide an index of downwelling of surface flow into artificial redds.

HYPOTHESES ON IMPROVING SPAWNING HABITAT

Hypothesis I-A: The density of fall-run chinook salmon redds will be higher in unconsolidated gravel in the project riffles than in the cemented gravel in the control riffles.

Redd density was significantly correlated with the distance downstream from Goodwin Dam and so comparisons between project sites and control sites were based on the regressions with distance downstream. Presumably adult salmon migrate upstream until they encounter a cue in the surface flow, such as suitable levels of dissolved oxygen or water temperature. Regardless of the cue used by the salmon to select a spawning site, their behavior results in relatively high redd densities at the upstream riffles and low redd densities at the downstream riffles. Therefore, to maximize the benefits of restoration, project sites should be selected within the reach typically used by high densities of spawners. In the Stanislaus River, the most highly used reaches during fall 1998 and fall 1999 occurred between Goodwin Dam and Willms Pond (Riffle R20).

Whether the density of redds was higher at project riffles than in control riffles also depended on the size and source of the restoration gravel. The density of redds was significantly greater at project riffles with Stanislaus River rock cleaned with a 1/4-inch screen than at the sites with Tuolumne River rock. Redd densities may also have been greater at the sites with Stanislaus River rock cleaned with a 3/8-inch screen and the control sites compared to the Tuolumne River rock sites, however the level of significance (P) was 0.073 and 0.096 respectively. Although the density of redds was substantially greater at the sites with Stanislaus River rock cleaned with a 1/4-inch screen compared to both the sites with the Stanislaus River rock cleaned with a 3/8-inch screen and the control sites, it is likely that the number of replicates were too few to show a significant difference.

Hypothesis I-B: The higher the elevation of a riffle's crest, the greater will be the rate of surface water downwelling that presumably helps attract spawners.

The elevation of the natural riffle's crest as measured under pre-project conditions had no measurable effect on downwelling rates in artificial redds, intragravel D.O. concentrations or the density of redds. Vertical hydraulic gradient (VHG), which is the measurement of downwelling rate used in this study, was near zero at all artificial redds in both project riffles and control riffles, regardless of the elevation of the riffle's crest. It is likely that the process of redd construction increases bed permeability to such a high level that downwelling occurs without sufficient resistance to produce a measurable hydraulic gradient. Furthermore, intragravel D.O.

concentrations were near saturation at most project riffles regardless of the elevation of the riffle's crest.

It was not possible to conduct a statistical analysis of the density of redds in riffles with differing crest elevations due to the low number of replicates and the confounding influences of gravel type and distance downstream. However, there were almost no differences in redd density between the high-crested, moderate-crested, and low-crested riffles near Lovers Leap that all received Stanislaus River rock washed with a 3/8-inch screen. The redd density was 0.175/yd² at Riffle R14A, which was high-crested, 0.154/yd² at Riffle R13, which was moderate crested, 0.177/yd² at Riffle R12A, which was low-crested, and 0.094/yd² at Riffle R19A, which was also low-crested. Although additional evidence is warranted, the fall 1999 data suggest that redd densities do not differ between riffles created by adding gravel to extensively mined channels, naturally flat channels, or preferred natural spawning sites at the tails of pools.

HYPOTHESES ON IMPROVING INCUBATION HABITAT

A critical review of the literature on salmonid egg survival to emergence indicates that estimates of egg survival to emergence based on habitat measurements, such as intragravel D.O. concentrations, apparent velocity, permeability, and the concentration of substrate fines, should be viewed with caution. Comparisons among previous studies suggest that egg survival to hatching is substantially affected by the adhesion of fine sediment to the egg's membranes although this presumed influence has not been quantified under field conditions. Furthermore, studies of alevin emergence rates have either used abnormally healthy alevins tested under laboratory conditions or failed to accurately estimate the initial number of viable eggs or the number of alevins that escaped from natural redds capped with netting, which makes it impossible to determine the accuracy of the egg survival to emergence estimates. Therefore, it is recommended for future studies that egg survival to emergence should be measured directly by planting eggs to determine the percentage of eggs that survive to hatching and also by determining emergence rates in natural redds, both at single and superimposed redds. Egg survival to hatching studies should monitor intragravel D.O. concentrations, apparent velocity, and water temperature. The turbidity of intragravel water should also be monitored to try to establish an index of the amount of fines adhering to egg membranes. Permeability measurements could be made at some lots of planted eggs by installing a permanent standpipe; however, pumping substrate fines from the artificial redd during measurements may confound the results and there may be few benefits from permeability measurements because previous studies suggest that permeability may not be well correlated with egg survival.

Entombment of alevins may be the greatest source of egg and alevin mortality in the Stanislaus River if salmon are able to create suitable egg incubation conditions during redd construction in both restoration and natural riffles as fall 1999 permeability measurements suggest, but a lack of spawning habitat causes high rates of redd superimposition that results in entombment of the alevins in the superimposed redd. Redd superimposition was common at many of the riffles between Goodwin Dam and Willms Pond (Riffle R20) in fall 1999 judging by the proximity of the redds in these riffles (Appendix 3). Entombment of alevins was not evaluated for this study and only limited data were collected for Task 6. Further study is recommended.

A suggestion for estimating emergence success at an individual redd is to divide the number of dead alevins entombed by the sum of the number of dead eggs adjusted by typical decomposition rates of dead eggs reported in the literature, the number of fry collected in emergence traps, and the number of entombed alevins. It may be possible to develop an index of emergence success based on the number of entombed alevins and the size of the female salmon. This index would be useful for comparing single redds with superimposed redds and comparing restoration sites with control sites. Such an index would be needed to assess emergence at superimposed redds since they cannot be individually capped without disturbing the superimposing redd. The utility of this index should be verified by extensively studying emergence at single redds as described above.

Hypothesis II-A: Adding gravel without fines to the streambed increases intragravel flow in redds.

Streambed permeability in the undisturbed beds of the riffles, which was used as a measure of intragravel flow for this study, was significantly greater at the project riffles where the restoration gravel was at least 12 inches deep than at the control sites throughout the fall 1999 incubation period. Furthermore, the permeability of the riffle bed was sufficient to nearly maximize ($\geq 80\%$) the expected survival of chinook salmon eggs to emergence based on laboratory studies at two-thirds of the locations sampled in the project sites in early February after several turbid rain storms. However, it is not possible to evaluate this hypothesis with the existing data because a sufficient number of redds were not measured. The process of redd construction greatly increases gravel permeability, particularly in the control riffles, and the permeability at redds was not routinely monitored in this study. Data were collected for Task 6 to evaluate this hypothesis.

After most of the eggs had incubated and the flood control releases began in mid February 2000, permeabilities increased at most project riffles but declined significantly at the upstream half of many project riffles in the Lovers Leap reach (riffles R13-R20) to levels that are similar to those at the control sites. It is possible that fine sediment was deposited at high rates at the riffles near Lovers Leap because this is an area of relatively recent and extensive gravel and gold mining. The Ohe Sand and Gravel quarry on the south side of the river near Riffle R14 is active and there was a quarry on the north side of the river that operated until about 1980. The source of the fines near Lovers Leap appears to be overflow from the quarries' washing ponds as evidenced by high rates of fine sediment deposition at two restoration riffles adjacent to the washing ponds at the Ohe Sand and Gravel quarry immediately following a rain storm in November 1999 that increased streamflow by only about 15 cfs. Fines were also deposited in project riffles R12A to R13, which are upstream from the active quarry, during flood control releases in February 2000. This suggests that past quarry activities and streambank erosion from cattle grazing, which occurs along short sections of the north bank of the Lovers Leap reach, were additional sources of fines. The relatively deep and wide channels that were mined in the Lovers Leap reach and other areas of the Stanislaus River store large volumes of fines and presumably the amount of stored fines is greater near Lovers Leap than in the other mined areas of the Stanislaus River.

Monitoring intragravel water temperatures in artificial redds and surface water temperatures provided data that were useful for detecting the timing and relative magnitude of fine sediment intrusion and the upwelling of oxygen-poor groundwater. Intragravel water temperatures rapidly changed after installation in mid October 1999 from closely matching surface water temperatures in magnitude and fluctuation to becoming elevated by 0.8 to 13 degrees Fahrenheit and relatively

stable at six artificial redds. The changes at these artificial redds were not related to changes in flow, storm runoff, or nearby redd construction. Five of these artificial redds occurred in control sites whereas one occurred within the restoration site at Riffle R58 where the redd was constructed in a mixture of restoration gravel and silty natural gravel. Four of the sites occurred near the Valley Oak Recreational Park where groundwater flows from gravel lenses perched above the river that are adjacent to houses with septic systems. Intragravel D.O. concentrations were less than 8 ppm, which probably would result in high rates of egg mortality, at the artificial redds where intragravel water temperatures were elevated by at least 0.8 degrees Fahrenheit. These site features suggest that the elevated and stabilized water temperatures resulted from fine sediment intrusion that decreased the ratio of surface flow downwelling to groundwater upwelling. Furthermore, the fine sediment intrusion probably resulted from the intragravel transport of fines within silty riffles during normal flow releases.

Intragravel water temperatures also became stabilized and slightly elevated at 44% of the artificial redds, usually beginning on 15 February 2000, which was one day after 1,500 cfs flood control releases began. About half of these sites occurred near Lovers Leap, where bed permeabilities significantly declined during the flood control releases. The mean intragravel D.O. concentration at these sites in late June and early July 2000 was 7.7 ppm, which was significantly different from the mean intragravel D.O. concentration of 9.3 ppm that was measured at the same time at the sites where no temperature deviations occurred.

Hypothesis II-B: Higher gradients of the streambed upstream of the hydraulic control at the riffle's crest result in higher rates of surface water downwelling that presumably increases intragravel dissolved oxygen concentrations.

All of the project riffles were created with similar bed gradients upstream of the hydraulic control and so this hypothesis cannot be evaluated with fall 1999 data.

Hypothesis II-C: The low percentage of fines in the project riffles will result in high intragravel D.O. concentrations relative to those at the control riffles, where the concentration of fines is high.

The intragravel D.O. concentration at the project sites was significantly greater than the concentrations measured at the control sites in mid-December 1999, which is when the eggs began to hatch, and in early February 2000, which is when most eggs had hatched. The mean D.O. concentration was 10.7 ppm at 68 artificial redds in the restoration sites and 9.3 ppm at 27 artificial redds in the control sites in mid-December. The mean D.O. concentration was 11.1 ppm at 31 artificial redds in the restoration sites and 9.7 ppm at 16 artificial redds in the control sites in early February 2000. The D.O. concentrations measured at 98.5% of the artificial redds in project riffles were probably sufficient to maximize the survival of chinook salmon eggs to hatching (≥ 8.0 ppm), whereas the D.O. concentrations measured in the control riffles would have produced high rates of survival at only 77.8% to 84.6% of the artificial redds. Furthermore, the high D.O. concentrations at the project riffles would have produced larger and healthier alevins that would be better able to emerge and compete for food after emergence than the fry produced at the control riffles.

HYPOTHESES ON THE SIZE AND SOURCE OF RESTORATION GRAVEL

Hypothesis III-A: Restoration gravel obtained from near the Stanislaus River will be used by more Stanislaus River chinook salmon than will gravel obtained from another watershed.

Redd densities at restoration sites with Stanislaus River rock washed with a 3/8-inch screen were about 70% higher than the redd densities at nearby restoration sites where similarly sized Tuolumne River rock was added. The comparison was based on the elevations (intercepts) of the regressions of redd density versus distance downstream, however, an *F*-test indicated that the difference was only moderately significant ($P = 0.073$). This difference is probably real because a comparison of redd densities between pre-project conditions in fall 1998 and the post-project conditions in fall 1999 within sites indicates that few salmon spawned where deep layers of Tuolumne River rock were placed whereas many salmon spawned where deep layers of Stanislaus River rock were placed. This also suggests that chinook salmon select spawning sites based on the odor of the rock because they were more likely to spawn in shallow layers of Tuolumne River rock where the scent of the underlying Stanislaus River rock may have attracted fish. This hypothesis will be evaluated further with fall 2000 data.

Hypothesis III-B: Restoration gravel between 3/8 inch and 5 inches will produce higher gravel permeabilities than will gravel between 1/4 inch and 5 inches.

Although the gravel washed with larger 3/8-inch screens had higher permeabilities than those washed with the 1/4-inch screen shortly after construction, the difference was statistically significant for only one of two comparisons. The gravel permeability at the riffles with Tuolumne River rock washed with a 3/8-inch screen was significantly greater than the gravel permeability at the riffles with Stanislaus River rock washed with a 1/4-inch screen. However, there was no significant difference between the riffles with Tuolumne River rock and riffles with similarly-sized Stanislaus River rock and there was no significant difference between the riffles that received the two sizes of Stanislaus River rock. Permeabilities measured in gravel at least 18-inches deep averaged 204,827 cm/hr for the Tuolumne River rock washed with a 3/8-inch screen, 171,436 cm/hr for the Stanislaus River rock washed with a 3/8-inch screen, and 150,990 cm/hr for Stanislaus River rock washed with a 1/4-inch screen. The difference between the Tuolumne River rock and the Stanislaus River rock washed with 3/8-inch screens was unexpected because the substrate size distributions were nearly identical for these two mixtures (CMC 2001).

Hypothesis III-C: Restoration gravel between 1/4 inch and 5 inches will attract more spawners than will gravel between 3/8 inch and 5 inches.

Mean redd densities were 29% higher at riffles with Stanislaus River rock cleaned with a 1/4-inch screen than at riffles with Stanislaus River rock cleaned with a 3/8-inch screen. However, an *F*-test indicated that neither the slopes ($P = 0.370$) nor the elevations ($P = 0.476$) of the regressions of redd densities versus distance downstream from Goodwin Dam were statistically different. Considering the magnitude of the differences, a greater number of replicates may have been needed to show significant differences. One possible explanation for why salmon may prefer to construct redds in gravel cleaned with a 1/4-inch screen is that small gravel between 1/4 and 3/8 inches in diameter may make redd construction easier by acting as a lubricant between the larger particles. Salmon frequently construct redds at piezometers sites where the cemented

streambed was loosened during the construction of artificial redds and it was easier to dig artificial redds with hoes and shovels in the gravel washed with 1/4-inch screens than in the gravel washed with 3/8-inch screens. Additional data were collected in fall 2000 to further evaluate this hypothesis.

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APPENDIX 1

USGS QUADRANGLES SHOWING SITE LOCATIONS

Figure 1. Knights Ferry Quadrangle showing the locations of riffles DFG2, TMA, TM1, R1, R5, R10, and R12 in the Stanislaus River.

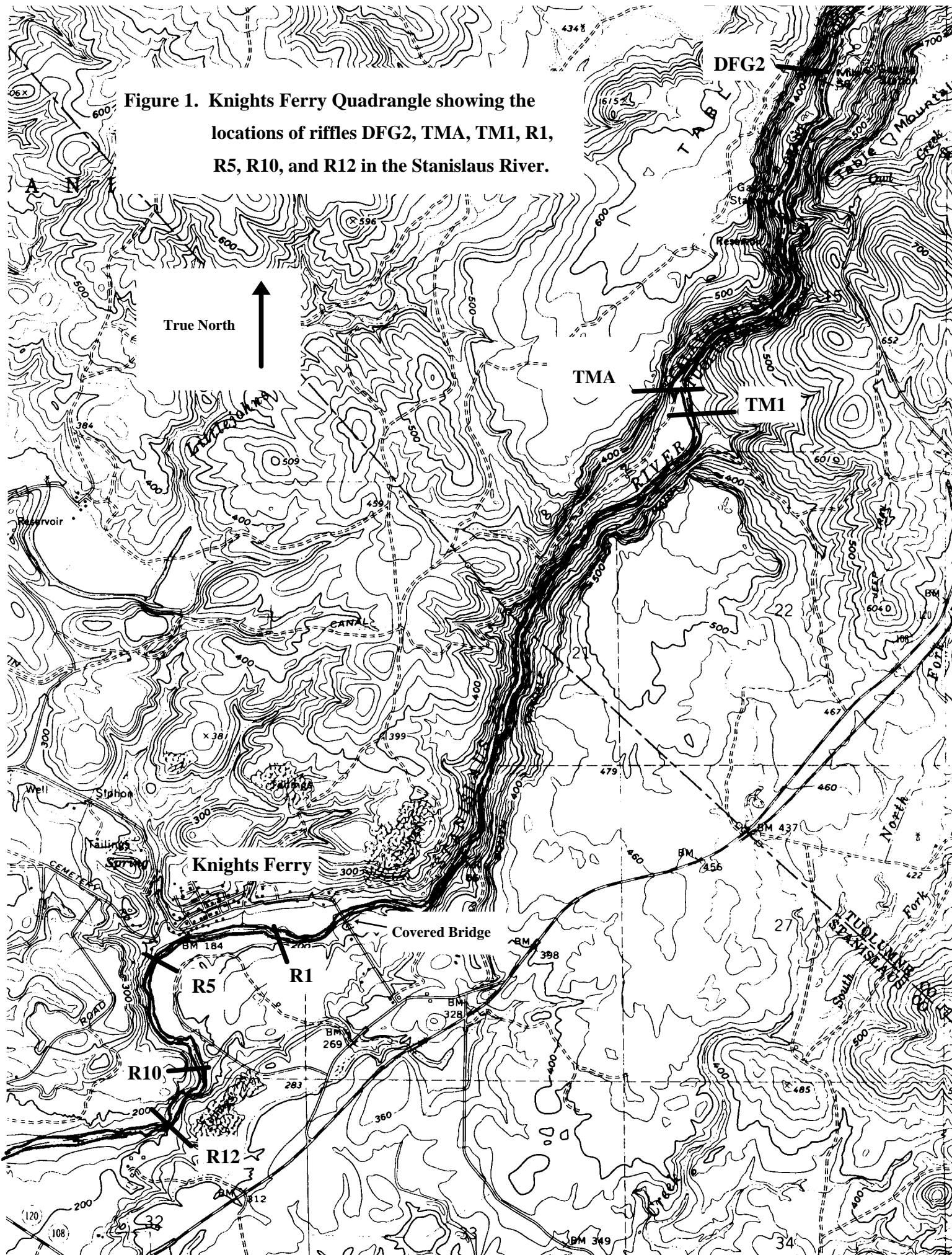


Figure 2. Knights Ferry Quadrangle showing the locations of riffles R12, R12A, R12B, R13, R14, R14A, R15, R16, R19, R19A, and R20 in the Stanislaus River

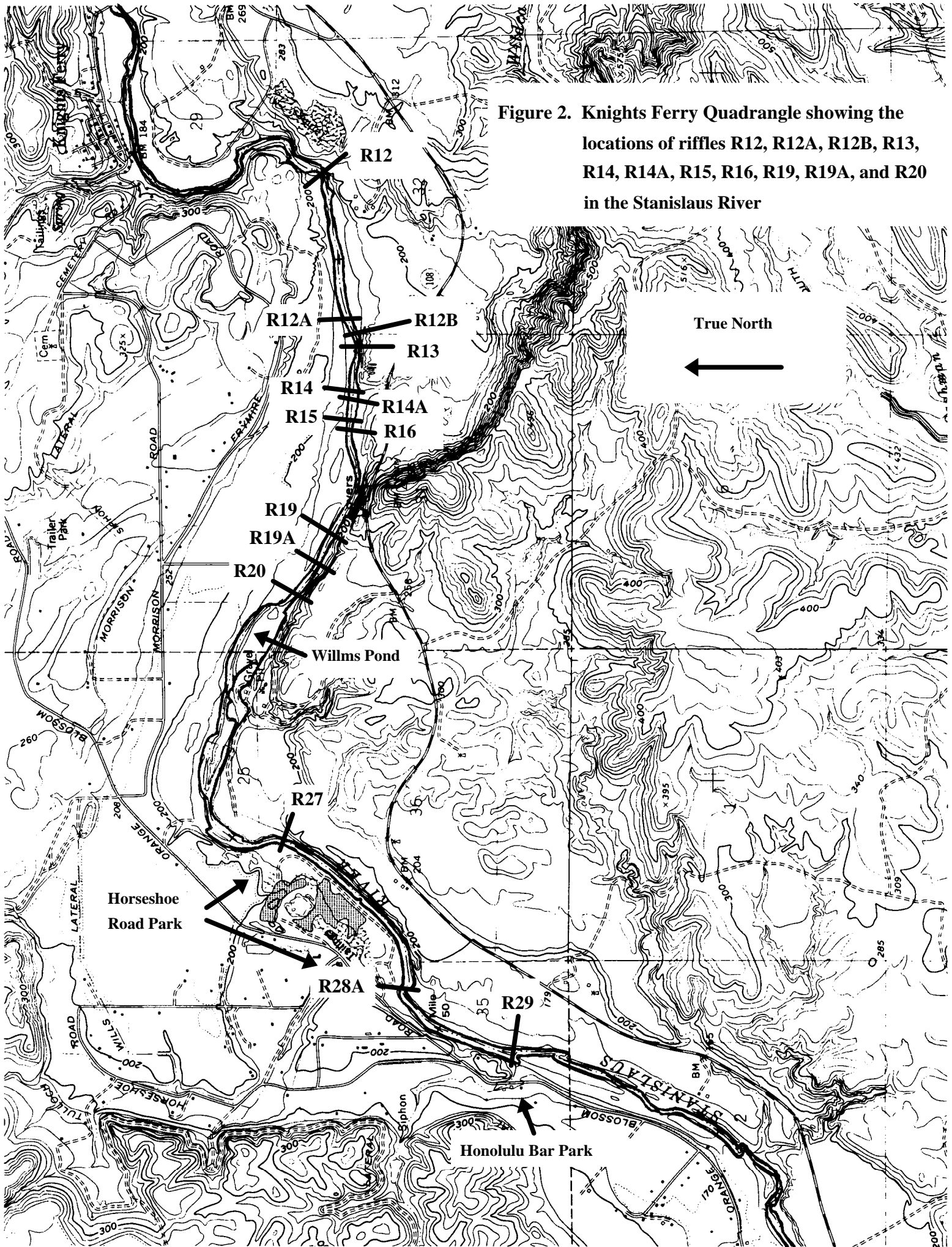


Figure 3. Oakdale Quadrangle showing the locations of riffles R43, R57, R58, and R59 in the Stanislaus River.

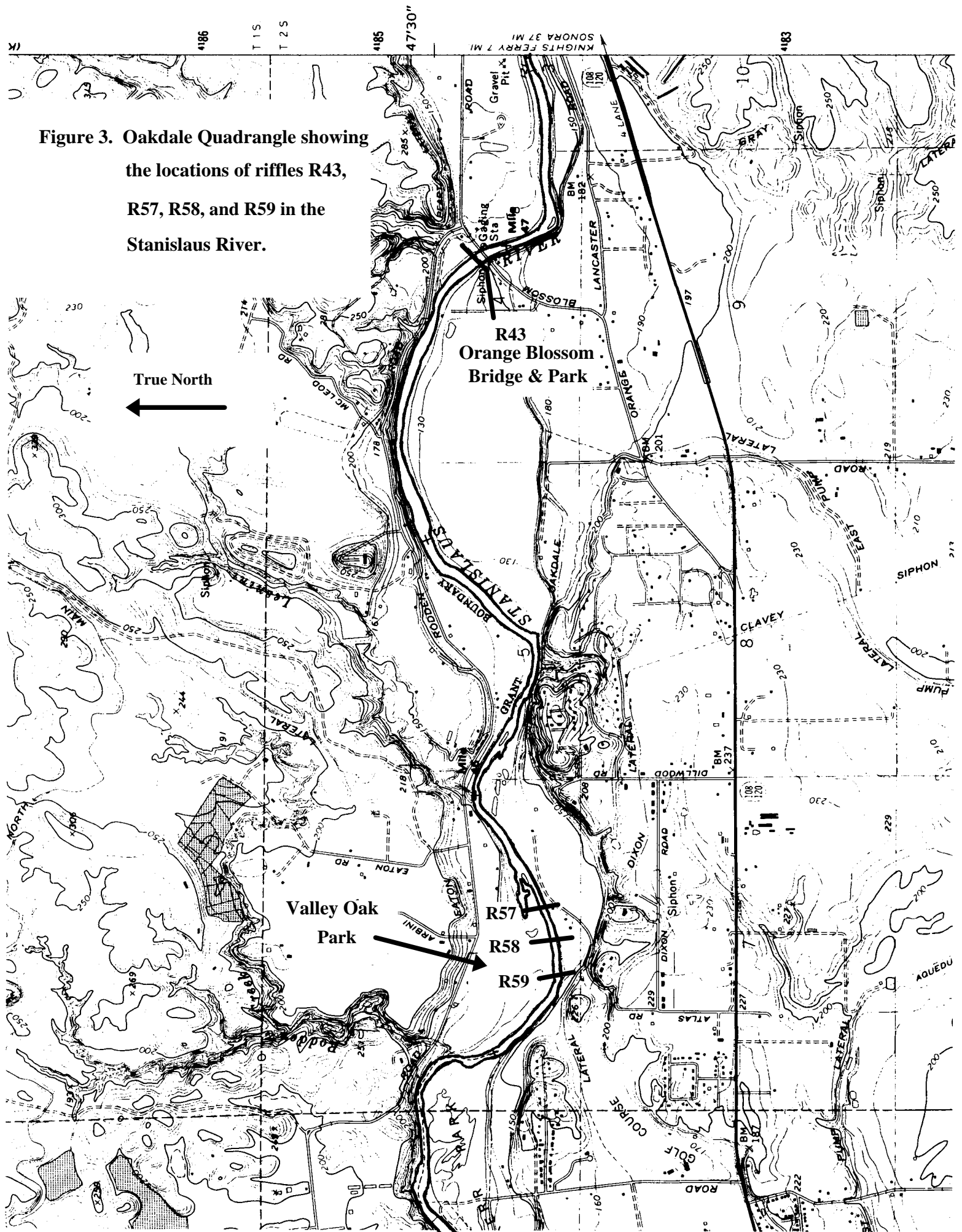
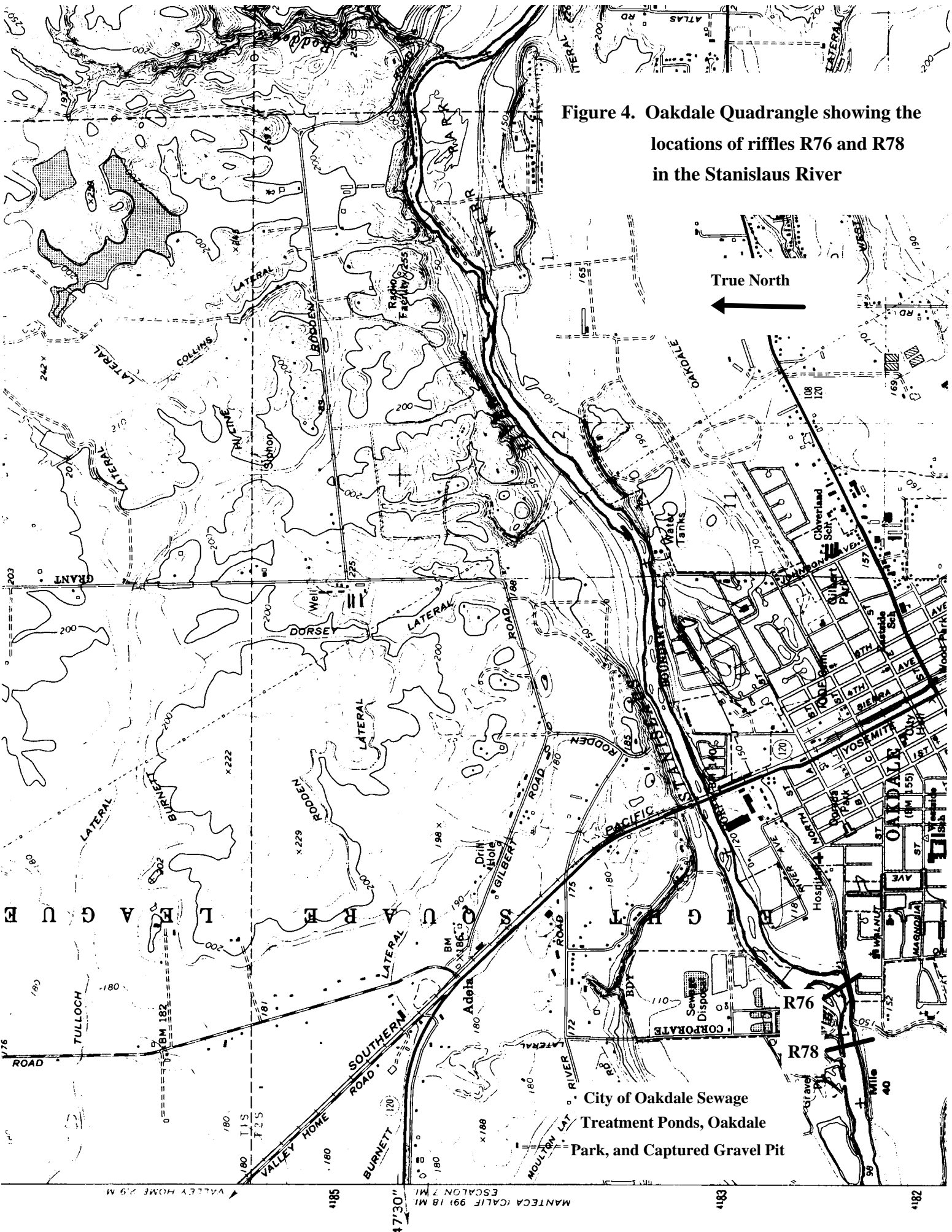


Figure 4. Oakdale Quadrangle showing the locations of riffles R76 and R78 in the Stanislaus River



APPENDIX 2

Tables 1-8 of Results

Table 1. The rivermile and streambed gradient upstream from the riffle's crest of the riffles selected for the,Knights Ferry Gravel Replenishment Project in the Stanislaus River and the amount of gravel placed at the 18 project riffles in August and September 1999. The seven control riffles were not altered.

A) High-Crested Riffles (Tails of Deep Pools), 3.4% to 17.7% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
TMA	56.8	Stanislaus River-Rock, 1/4 to 5 inch diameter	840	470	6.9%
TM1	56.6	Control Riffle, No Gravel Added	--	--	4.3%
R1	54.55	Stanislaus River-Rock, 3/8 to 5 inch diameter	550	395	10.5%
R12	53.3	Control Riffle, No Gravel Added	--	--	3.4%
R14A	52.57	Stanislaus River-Rock, 3/8 to 5 inch diameter	1,430	1,055	5.4%
R28A	50.2	Stanislaus River-Rock, 1/4 to 5 inch diameter	450	250	5.2%
R29	49.75	Tuolumne River-Rock, 3/8 to 5 inch diameter	300	210	4.7%
R76	40.35	Control Riffle, No Gravel Added	--	--	17.7%
B) Moderate-Crested Riffles, 1.6 to 3% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
R13	52.73	Stanislaus River-Rock, 3/8 to 5 inch diameter	1,200	860	1.7%
R15	52.51	Tuolumne River-Rock, 3/8 to 5 inch diameter	860	610	2.4%
R16	52.48	Tuolumne River-Rock, 3/8 to 5 inch diameter	330	240	2.8%
R20	51.8	Control Riffle, No Gravel Added	--	--	1.6%
R27	50.8	Control Riffle, No Gravel Added	--	--	2.9%
R43	46.9	Tuolumne River-Rock, 3/8 to 5 inch diameter	440	315	2.0%
R58	44.5	Stanislaus River-Rock, 1/4 to 5 inch diameter	840	465	3.0%
R78	40.2	Tuolumne River-Rock, 3/8 to 5 inch diameter	570	405	2.5%
C) Low-Crested Riffles, 0 to 1.5% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
R5	53.9	Tuolumne River-Rock, 3/8 to 5 inch diameter	440	315	-0.4%
R10	53.5	Control Riffle, No Gravel Added	--	--	0.5%
R12A	52.82	Stanislaus River-Rock, 3/8 to 5 inch diameter	540	380	0.9%
R12B	52.77	Stanislaus River-Rock, 1/4 to 5 inch diameter	850	470	1.5%
R14	52.6	Stanislaus River-Rock, 1/4 to 5 inch diameter	835	465	1.3%
R19	52.13	Stanislaus River-Rock, 1/4 to 5 inch diameter	675	130	0.6%
R19A	52.06	Stanislaus River-Rock, 3/8 to 5 inch diameter	950	680	0.5%
R57	44.6	Stanislaus River-Rock, 3/8 to 5 inch diameter	900	645	0.1%
R59	44.4	Control Riffle, No Gravel Added	--	--	-0.5%

Table 2. Table for converting field inflow rate (ml/s) measurements in 0.1 increments to permeability (cm/hr).

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
2	80	110	120	150	160	170	175	180	185	190
3	195	210	220	230	240	250	260	270	280	285
4	290	305	310	320	330	340	350	360	370	380
5	390	405	415	430	440	450	465	475	485	490
6	500	505	515	530	540	550	565	575	585	590
7	600	605	615	630	640	650	665	675	685	690
8	705	710	720	730	740	750	765	785	795	800
9	810	815	825	835	845	850	860	870	880	885
10	890	905	920	935	950	960	970	980	990	1000
11	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190
12	1200	1210	1220	1230	1240	1250	1260	1270	1280	1290
13	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390
14	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490
15	1500	1510	1520	1530	1540	1550	1560	1570	1580	1590
16	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690
17	1700	1710	1720	1730	1740	1750	1760	1770	1780	1790
18	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890
19	1900	1915	1930	1940	1950	1960	1970	1980	1990	2000
20	2020	2070	2100	2120	2140	2150	2160	2170	2180	2190
21	2200	2210	2220	2230	2240	2250	2260	2270	2280	2290
22	2300	2310	2320	2330	2340	2350	2360	2370	2380	2390
23	2400	2410	2420	2430	2440	2450	2460	2470	2480	2490
24	2500	2510	2520	2530	2540	2550	2560	2570	2580	2590
25	2600	2610	2620	2630	2640	2650	2660	2670	2680	2690
26	2700	2710	2720	2730	2740	2750	2760	2770	2780	2790
27	2800	2810	2820	2830	2840	2850	2860	2870	2880	2890
28	2900	2910	2920	2930	2940	2950	2960	2970	2980	2990
29	3000	3010	3020	3030	3040	3050	3060	3070	3080	3090
30	3100	3120	3140	3160	3180	3200	3220	3240	3260	3280
31	3300	3340	3380	3420	3450	3480	3510	3540	3560	3580
32	3600	3620	3640	3660	3680	3700	3720	3740	3760	3780
33	3800	3820	3840	3860	3880	3900	3920	3940	3960	3980
34	4000	4020	4040	4060	4080	4100	4120	4140	4160	4180
35	4200	4220	4240	4260	4280	4300	4320	4340	4360	4380
36	4400	4420	4440	4460	4480	4500	4520	4540	4560	4580
37	4600	4610	4620	4630	4640	4650	4660	4670	4680	4690
38	4700	4710	4720	4730	4740	4750	4760	4770	4780	4790
39	4800	4810	4820	4830	4840	4850	4860	4870	4880	4890
40	4900	4910	4920	4930	4940	4950	4960	4970	4980	4990

Table 2 (Continued)

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
41	5100	5120	5140	5160	5180	5200	5220	5240	5260	5280
42	5300	5320	5340	5360	5380	5400	5420	5440	5460	5480
43	5400	5420	5440	5460	5480	5500	5520	5540	5560	5580
44	5500	5520	5540	5560	5580	5600	5620	5640	5660	5680
45	5600	5620	5640	5660	5680	5700	5720	5740	5760	5780
46	5700	5720	5740	5760	5780	5800	5820	5840	5860	5880
47	5800	5820	5840	5860	5880	5900	5920	5940	5960	5980
48	6000	6050	6100	6140	6180	6220	6260	6300	6340	6380
49	6400	6450	6500	6540	6580	6620	6660	6700	6740	6780
50	6800	6830	6860	6890	6920	6950	6980	7010	7040	7070
51	7100	7130	7160	7190	7220	7250	7280	7310	7340	7370
52	7400	7450	7500	7540	7580	7620	7660	7700	7740	7780
53	7800	7850	7900	7940	7980	8020	8060	8100	8140	8181
54	8200	8250	8300	8340	8380	8420	8460	8500	8540	8580
55	8600	8650	8700	8740	8780	8820	8860	8900	8940	8980
56	9000	9050	9100	9140	9180	9220	9260	9300	9340	9380
57	9400	9430	9460	9490	9520	9550	9580	9610	9640	9670
58	9700	9730	9760	9790	9820	9850	9880	9910	9940	9970
59	10000	10030	10060	10090	10120	10150	10180	10210	10240	10270
60	10300	10350	10400	10440	10480	10520	10560	10600	10640	10680
61	10700	10730	10760	10790	10820	10850	10880	10910	10940	10970
62	11000	11030	11060	11090	11120	11150	11180	11210	11240	11270
63	11300	11330	11360	11390	11420	11450	11480	11510	11540	11570
64	11600	11650	11700	11740	11780	11820	11860	11900	11940	11980
65	12000	12050	12100	12140	12180	12220	12260	12300	12340	12380
66	12400	12450	12500	12540	12580	12620	12660	12700	12740	12780
67	12800	12850	12900	12940	12980	13020	13060	13100	13140	13180
68	13200	13250	13300	13340	13380	13420	13460	13500	13540	13580
69	13600	13650	13700	13740	13780	13820	13860	13900	13940	13980
70	14000	14060	14120	14180	14240	14300	14360	14420	14480	14540
71	14600	14660	14720	14780	14840	14900	14960	15020	15080	15140
72	15200	15270	15340	15410	15480	15550	15620	15690	15760	15830
73	15900	15970	16140	16110	16180	16250	16320	16390	16460	16530
74	16600	16670	16740	16810	16880	16950	17020	17090	17160	17230
75	17300	17370	17440	17510	17580	17650	17720	17790	17860	17930
76	18000	18070	18140	18210	18280	18350	18420	18490	18560	18630
77	18700	18770	18840	18910	18980	19050	19120	19190	19260	19330
78	19400	19480	19560	19640	19720	19800	19880	19960	20040	20120
79	20200	20280	20360	20440	20520	20600	20680	20760	20840	20920
80	21000	21200	21400	21600	21800	22000	22200	22400	22600	22800

Table 2 (Continued)

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
81	23000	23150	23300	23450	23600	23750	23900	24050	24200	24350
82	24500	24650	24800	24950	25100	25250	25400	25550	25700	25850
83	26000	26100	26200	26300	26400	26500	26600	26700	26800	26900
84	27000	27100	27200	27300	27400	27500	27600	27700	27800	27900
85	28000	28100	28200	28300	28400	28500	28600	28700	28800	28900
86	29000	29100	29200	29300	29400	29500	29600	29700	29800	29900
87	30000	30100	30200	30300	30400	30500	30600	30700	30800	30900
88	31000	31100	31200	31300	31400	31500	31600	31700	31800	31900
89	32000	32100	32200	32300	32400	32500	32600	32700	32800	32900
90	33000	33300	33600	33900	34200	34500	34800	35100	35400	35700
91	36000	36300	36600	36900	37200	37500	37800	38100	38400	38700
92	39000	39100	39200	39300	39400	39500	39600	39700	39800	39900
93	40000	40100	40200	40300	40400	40500	40600	40700	40800	40900
94	41000	41100	41200	41300	41400	41500	41600	41700	41800	41900
95	42000	42100	42200	42300	42400	42500	42600	42700	42800	42900
96	43000	43100	43200	43300	43400	43500	43600	43700	43800	43900
97	44000	44100	44200	44300	44400	44500	44600	44700	44800	44900
98	45000	45100	45200	45300	45400	45500	45600	45700	45800	45900
99	46000	46100	46200	46300	46400	46500	46600	46700	46800	46900
100	47000	47500	48000	48500	49000	49500	50000	50500	51000	51500
101	52000	52600	53200	53800	54400	55000	55600	56200	56800	57400
102	58000	58600	59200	59800	60400	61000	61600	62200	62800	63400
103	64000	64600	65200	65800	66400	67000	67600	68200	68800	69400
104	70000	70500	71000	71500	72000	72500	73000	73500	74000	74500
105	75000	75500	76000	76500	77000	77500	78000	78500	79000	79500
106	80000	80500	81000	81500	82000	82500	83000	83500	84000	84500
107	85000	85500	86000	86500	87000	87500	88000	88500	89000	89500
108	90000	90500	91000	91500	92000	92500	93000	93500	94000	94500
109	95000	95500	96000	96500	97000	97500	98000	98500	99000	99500
110	100000	100500	101000	101500	102000	102500	103000	103500	104000	104500

Table 3 The number of fall-run chinook salmon redds, riffle area, density of redds, and distance below Goodwin Dam for the 25 KFGRP riffles in the Stanislaus River in fall 1999. The project riffles were segregated into two areas. One area is where gravel was placed in fall 1999 as shown as the area within the polygons in the contour maps in Appendix 3; these areas are referred to as “inside” in the table’s subheading below. The other area was immediately adjacent to where the gravel was added and is outside the polygons in the contour maps; these areas are referred to as “outside” in the table’s subheading below. The areas used by spawners at the control sites are also referred to as “outside” in the table below.

<u>Site</u>	<u>Number of Redds</u>		<u>Riffle Area (square-yards)</u>		<u>Redds/yd²</u>		<u>Location Miles Below Goodwin Dam</u>
	<u>Inside</u>	<u>Outside</u>	<u>Inside</u>	<u>Outside</u>	<u>Inside</u>	<u>Outside</u>	
TMA	120	7	256	118	0.469	0.059	1.70
TM1*	--	89	--	347		0.256	1.90
R1	107	20	282	70	0.379	0.286	3.95
R5	25	9	123	38	0.203	0.239	4.60
R10*	--	69	--	516	--	0.134	5.00
R12*	--	34	--	138	--	0.247	5.20
R12A	22	26	114	123	0.193	0.211	5.65
R12B	53	17	164	89	0.298	0.19	5.73
R13	55	--	341	--	0.161	--	5.77
R14	94	29	436	119	0.216	0.243	5.90
R14A	35	50	137	495	0.255	0.101	5.93
R15	10	4	175	26	0.057	0.152	5.99
R16	23	1	154	13	0.150	0.076	6.02
R19	78	75	316	419	0.247	0.179	6.37
R19A	24	--	193	--	0.124	--	6.44
R20*	--	207	--	1021	--	0.203	6.70
R27*	--	41	--	217	--	0.189	7.70
R28A	10	2	111	12	0.090	0.169	8.30
R29	8	8	107	96	0.075	0.083	8.75
R43	5	19	143	277	0.035	0.069	11.60
R57	15	--	191	--	0.079	--	13.90
R58	19	2	392	13	0.048	0.159	14.00
R59*	--	0	--	259	--	0.000	14.10
R76*	--	2	--	126	--	0.016	18.15
R78	0	0	291	190	0.000	0.000	18.30
Total	703	711	--	--	--	--	--
Average	--	--	218	214	0.172	0.148	--

* control sites

Table 4. The results of the F-test for each pair of regressions tested. The F-test requires that the variances of the regressions are not significantly different ($P > 0.05$) before the slopes are compared. If the slopes are not significantly different ($P > 0.05$), then the elevations can be compared. The probability of the final test for each set of comparisons are shown in bold font.

Comparison	<i>F</i> -statistic	df	<i>P</i>
Stanislaus River rock 1/4-inch screen vs Tuolumne River rock			
Equality of Variances	2.33	5, 4	0.217
Slopes	3.72	1, 9	0.086
Elevations	5.64	1, 10	0.039
Stanislaus River rock 3/8-inch screen vs Tuolumne River rock			
Equality of Variances	2.22	5, 4	0.231
Slopes	0.87	1, 9	0.376
Elevations	4.03	1, 10	0.073
Tuolumne River rock vs Control Sites			
Equality of Variances	1.04	4, 5	0.468
Slopes	0.67	1, 9	0.434
Elevations	3.37	1, 10	0.096
Stanislaus River rock 1/4-inch screen vs Stan 3/8-inch screen			
Equality of Variances	1.05	5, 5	0.479
Slopes	0.88	1, 10	0.370
Elevations	0.54	1, 11	0.476
Stanislaus River rock 1/4-inch screen vs Control Sites			
Equality of Variances	2.43	5, 5	0.176
Slopes	2.29	1, 10	0.162
Elevations	2.19	1, 11	0.167
Stanislaus River rock 3/8-inch screen vs Control Sites			
Equality of Variances	2.31	5, 5	0.189
Slopes	0.14	1, 10	0.721
Elevations	0.53	1, 11	0.483

Table 5. Streambed permeability (PERM) measured at a depth of 12 inches in undisturbed gravel approximately 18 inches from the piezometer (P) sites at 18 project riffles and seven control riffles in the Stanislaus River between Goodwin Dam and Oakdale during four surveys between October 1999 and July 2000. The depth of the restoration gravel at the sampling location and the estimated percent survival to emergence (% SURV) based on McCuddin's 1977 study are also presented.

Site	Gravel Type, Gravel Depth at Standpipe	27 Oct - 1 Nov 99		14 - 19 Dec 99		6 - 9 Feb 00		27 Jun - 5 Jul 00	
		PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV
DFG2-P1	1997 Restoration	179,540	88	32,390	84	43,648	88	--	
DFG2-P2	1997 Restoration	165,215	88	9,816	62	43,055	88	--	
DFG2-P3	1997 Restoration	--		77,519	88	28,045	82	--	
DFG2-P4	1997 Restoration	103,618	88	67,348	88	98,750	88	--	
TMA-P1	Stanislaus 1/4" Screen, >18"	--		245,813	88	85,913	88	--	
TMA-P2	Stanislaus 1/4" Screen, >18"	--		203,895	88	60,830	88	--	
TMA-P3	Stanislaus 1/4" Screen, 6-12"	--		6,065	53	31,699	84	--	
TMA-P4	Stanislaus 1/4" Screen, 6-12"	--		212,693	88	31,403	84	--	
TM1-P1	Control Site-Natural	1,677	29	2,173	34	4,730	48	--	
TM1-P2	Control Site-Natural	1,440	26	707	13	385	2	--	
TM1-P3	Control Site-Natural	--		6,909	55	2,933	39	--	
TM1-P4	Control Site-Natural	512	7	759	14	< 70	0	--	
TM1-P5	Control Site-Natural	--	--	4,613	48	1,925	32	--	
R1-P1	Stanislaus 3/8" Screen, >18"	113,280	88	4,650	48	1,541	27	< 70	0
R1-P2	Stanislaus 3/8" Screen, >18"	299,040	88	193,500	88	23,156	78	93,888	88
R1-P3	Stanislaus 3/8" Screen, 6-12"	15,062	70	31,800	84	117	0	< 70	0
R1-P4	Stanislaus 3/8" Screen, 6-12"	2,822	39	1,830	31	731	14	439	4
R1-P5	Stanislaus 3/8" Screen, > 18"	--		--		--		12,821	67
R5-P1	Tuolumne 3/8" Screen, > 18"	--		31,700	84	41,969	88	675	12
R5-P2	Tuolumne 3/8" Screen, > 18"	--		141,000	88	63,793	88	137,363	88
R5-P3	Tuolumne 3/8" Screen, > 18"	--		142,500	88	35,846	86	111,463	88
R5-P4	Tuolumne 3/8" Screen, > 18"	--		114,000	88	39,006	88	86,488	88
R5-P5	Tuolumne 3/8" Screen, > 18"			93,000	88	--		--	

Table 5. Continued

<u>Site</u>	<u>Gravel Type, Gravel Depth at Standpipe</u>	<u>27 Oct - 1 Nov 99</u>		<u>14 - 19 Dec 99</u>		<u>6 - 9 Feb 00</u>		<u>27 Jun - 5 Jul 00</u>	
		<u>PERM (cm/hr)</u>	<u>% SURV</u>	<u>PERM (cm/hr)</u>	<u>% SURV</u>	<u>PERM (cm/hr)</u>	<u>% SURV</u>	<u>PERM (cm/hr)</u>	<u>% SURV</u>
R10-P1	Control Site-Natural	5,226	50	97,763	77	5,655	52	--	
R10-P2	Control Site-Natural			110,600	77	40,627	77	--	
R10-P3	Control Site-Natural	4,681	48	33,476	77	2,663	38	--	
R10-P4	Control Site-Natural	1,809	30	1,521	27	936	18	--	
R12-P1	Control Site-Natural	8,723	60	1,940	32	814	16	--	
R12-P2	Control Site-Natural	38,512	77	4,840	49	1,229	23	--	
R12-P3	Control Site-Natural	2,821	39	100,000	77	2,681	38	--	
R12-P4	Control Site-Natural	154,013	77	113,000	77	790	15	--	
R12A-P1	Stanislaus 3/8" Screen, > 18"	4,692	48	171,500	88	33,053	85	98	0
R12A-P2	Stanislaus 3/8" Screen, > 18"	36,815	87	198,000	88	49,238	88	3,866	45
R12A-P3	Stanislaus 3/8" Screen, > 18"	155,863	88	201,500	88	41,145	88	122,168	88
R12A-P4	Stanislaus 3/8" Screen, > 18"	91,113	88	226,000	88	42,705	88	115,455	88
R12B-P1	Stanislaus 1/4" Screen, > 18"	176,675	88	11,390	65	3,686	44	823	16
R12B-P2	Stanislaus 1/4" Screen, > 18"	156,620	88	134,500	88	38,123	87	12,799	67
R12B-P3	Stanislaus 1/4" Screen, > 18"	177,630	88	173,000	88	31,590	84	117,693	88
R12B-P4	Stanislaus 1/4" Screen, > 18"	174,765	88	191,000	88	31,493	84	1,477	27
R13-P1	Stanislaus 3/8" Screen, > 18"	145,638	88	163,000	88	41,543	88	5,430	51
R13-P2	Stanislaus 3/8" Screen, > 18"	198,163	88	233,500	88	44,312	88	256	0
R13-P3	Stanislaus 3/8" Screen, > 18"	192,910	88	238,500	88	44,503	88	41,800	88
R13-P4	Stanislaus 3/8" Screen, > 18"	160,440	88	212,000	88	35,240	85.8	1,091	21
R14-P1	Stanislaus 1/4" Screen, ~12"	68,620	88	33,476	85	--		43,500	88
R14-P2	Stanislaus 1/4" Screen, 6-12"	649	11	4,592	48	--		2,033	33
R14-P3	Stanislaus 1/4" Screen, 6-12"	161,210	88	11,129	64	--		14,300	69
R14-P4	Stanislaus 1/4" Screen, 6-12"	1,325	25	385	2	--		409	3

Table 5. Continued

<u>Site</u>	Gravel Type, Gravel Depth at Standpipe	<u>27 Oct - 1 Nov 99</u>		<u>14 - 19 Dec 99</u>		<u>6 - 9 Feb 00</u>		<u>27 Jun - 5 Jul 00</u>	
		PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV
R14A-P1	Stanislaus 3/8" Screen, > 18"	221,840	88	159,975	88	--		41,258	88
R14A-P2	Stanislaus 3/8" Screen, > 18"	204,920	88	139,731	88	--		15,451	70
R14A-P3	Stanislaus 3/8" Screen, > 18"	183,703	88	121,463	88	--		2,181	34
R14A-P4	Stanislaus 3/8" Screen, > 18"	178,130	88	212,806	88	--		1,280	24
R15-P1	Tuolumne 3/8" Screen, > 18"	224,845	88	19,720	75	--		95,025	88
R15-P2	Tuolumne 3/8" Screen, > 18"	228,705	88	25,700	80	--		87,785	88
R15-P3	Tuolumne 3/8" Screen, > 18"	213,885	88	30,200	83	--		3,457	43
R15-P4	Tuolumne 3/8" Screen, > 18"	216,160	88	19,880	75	--		1,005	20
R16-P1	Tuolumne 3/8" Screen, ~12"	4,445	47	805	15	--		453	5
R16-P2	Tuolumne 3/8" Screen, ~12"	48,000	88	18,052	73	--		79,200	88
R16-P3	Tuolumne 3/8" Screen, 6-12"	1,824	31	1,313	24	--		845	16
R16-P4	Tuolumne 3/8" Screen, 6-12"	37,536	87	15,563	71	--		15,409	70
R19-P1	Stanislaus 1/4" Screen, ~12"	1,757	30	3,050	40	--		1,496	27
R19-P2	Stanislaus 1/4" Screen, ~12"	802	15	2,770	38	--		2,245	34
R19-P3	Stanislaus 1/4" Screen, ~12"	204,000	88	3,940	45	--		57,246	88
R19-P4	Stanislaus 1/4" Screen, ~12"	159,485	88	5,680	52	--		1,666	29
R19A-P1	Stanislaus 3/8" Screen, > 18"	163,090	88	45,200	88	--		7,276	56
R19A-P2	Stanislaus 3/8" Screen, > 18"	161,680	88	74,500	88	--		101,910	88
R19A-P3	Stanislaus 3/8" Screen, > 18"	145,230	88	50,000	88	--		9,666	62
R19A-P4	Stanislaus 3/8" Screen, > 18"	149,930	88	36,300	86	--		78,690	88
R20-P1	Control Site-Natural	9,344	61	44,635	77	--		430	4
R20-P2	Control Site-Natural	1,109	21	696	13	--		< 70	0
R20-P3	Control Site-Natural	755	14	3,614	43	--		40,076	77
R20-P4	Control Site-Natural	705	13	15,938	71	--		417	3

Table 5. Continued

Site	Gravel Type, Gravel Depth at Standpipe	27 Oct - 1 Nov 99		14 - 19 Dec 99		6 - 9 Feb 00		27 Jun - 5 Jul 00	
		PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV	PERM (cm/hr)	% SURV
R27-P1	1994 Restoration	43,680	77	3,180	41	12,695	67	< 70	0
R27-P2	1994 Restoration	189,026	77	2,690	38	12,071	66	4,749	48
R27-P3	1994 Restoration	192,095	77	40,800	77	5,129	50	10,862	64
R27-P4	1994 Restoration	78,490	77	23,600	77	8,249	59	37,806	77
R28A-P1	Stanislaus 1/4" Screen, > 18"	178,080	88	121,463	88	54,233	88	92,199	88
R28A-P2	Stanislaus 1/4" Screen, > 18"	158,400	88	130,350	88	62,339	88	75,780	88
R28A-P3	Stanislaus 1/4" Screen, > 18"	102,185	88	52,535	88	39,758	88	5,751	52
R28A-P4	Stanislaus 1/4" Screen, > 18"	83,563	88	30,218	83	5,308	50	1,339	25
R29-P1	Tuolumne 3/8" Screen, ~12"	165,120	88	92,825	88	77,025	88	--	
R29-P2	Tuolumne 3/8" Screen, ~12"	161,638	88	207	0	1,287	24	--	
R29-P3	Tuolumne 3/8" Screen, 6-12"	39,648	88	75,050	88	8,327	59	--	
R29-P4	Tuolumne 3/8" Screen, 6-12"	3,782	44	696	13	1,901	31	--	
R43-P1	Tuolumne 3/8" Screen, > 18"	205,440	88	115,313	88	44,217	88	106,092	88
R43-P2	Tuolumne 3/8" Screen, > 18"	139,925	88	164,513	88	63,985	88	95,567	88
R43-P3	Natural	879	17	4,859	49	258	0	--	
R43-P4	Natural	2,297	35	5,453	51	3,514	43	--	
R57-P1	Stanislaus 3/8" Screen, > 18"	174,288	88	126,588	88	--		957	19
R57-P2	Stanislaus 3/8" Screen, > 18"	187,200	88	120,950	88	--		61,050	88
R57-P3	Stanislaus 3/8" Screen, > 18"	158,053	88	107,625	88	--		63,525	88
R57-P4	Stanislaus 3/8" Screen, > 18"	144,205	88	86,100	88	--		28,215	82
R58-P1	Stanislaus 1/4" Screen, ~12"	149,935	88	96,350	88	--		1,666	29
R58-P2	Stanislaus 1/4" Screen, ~12"	9,248	61	163,488	88	--		4,605	48
R58-P3	Stanislaus 1/4" Screen, 6-12"	1,528	27	2,542	37	--		< 70	0
R58-P4	Stanislaus 1/4" Screen, 6-12"	819	16	4,100	46	--		362	0.4

Table 5. Continued

<u>Site</u>	<u>Gravel Type, Gravel Depth at Standpipe</u>	<u>27 Oct - 1 Nov 99</u>		<u>14 - 19 Dec 99</u>		<u>6 - 9 Feb 00</u>		<u>27 Jun - 5 Jul 00</u>	
		<u>PERM (cm/hr)</u>	<u>% SURV</u>	<u>PERM (cm/hr)</u>	<u>% SURV</u>	<u>PERM (cm/hr)</u>	<u>% SURV</u>	<u>PERM (cm/hr)</u>	<u>% SURV</u>
R59-P1	Control Site-Natural	685	12	4,220	46	--		70	0
R59-P2	Control Site-Natural	1,582	28	2,490	36	--		202	0
R59-P3	Control Site-Natural	3,502	43	1,550	28	--		211	0
R59-P4	Control Site-Natural	5,211	50	4,630	48	--		572	9
R76-P1	Control Site-Natural	14,459	69	1,980	32	--		15,939	71
R76-P2	Control Site-Natural	--		52,000	77	--		640	11
R76-P3	Control Site-Natural	3,916	45	4,810	49	--		535	8
R76-P4	Control Site-Natural	1,677	29	4,770	49	--		394	2
R78-P1	Tuolumne 3/8" Screen, 6-12"	747	14	4,790	49	--		474	5
R78-P2	Tuolumne 3/8" Screen, ~12"	207,713	88	91,500	88	--		2,384	36
R78-P3	Tuolumne 3/8" Screen, 6-12"	121,285	88	46,500	88	--		404	2
R78-P4	Tuolumne 3/8" Screen, ~12"	222,038	88	2,680	38	--		941	18

Table 6. Intragravel and surface dissolved oxygen concentrations in parts-per-million (ppm) at piezometers (P) at 18 project riffles and seven control riffles in the Stanislaus River between Goodwin Dam and Oakdale during nine surveys between October 1999 and February 2000. Measurements during the 18-23 October survey were typically made about 10 to 30 minutes after the piezometers were installed. Measurements during the 26 January and 6-9 February 2000 surveys were made following turbid storm runoff.

<u>Site</u>	<u>18-23 Oct</u>	<u>27 Oct 1 Nov</u>	<u>5-10 Nov</u>	<u>13-18 Nov</u>	<u>26-28 Nov</u>	<u>4-6 Dec</u>	<u>14-19 Dec</u>	<u>26 Jan</u>	<u>6-9 Feb</u>
DFG2-P1	11.2	11.2	10.2	9.3	10.0	9.6	11.6	--	10.9
DFG2-P2	11.6	11.2	10.2	--	--	--	--	--	11.1
DFG2-P3	--	--	--	--	--	--	--	--	10.8
DFG2-P4	11.2	10.6	10.3	10.0	--	--	--	--	10.9
DFG2-Surface	11.9	11.1	10.8	10.8	11.2	10.9	11.7	--	11.4
TMA-P1	11.7	10.9	11.0	10.2	10.5	10.9	11.5	--	11.1
TMA-P2	11.6	10.6	10.4	10.0	10.0	10.4	11.5	--	--
TMA-P3	12.1	10.9	10.8	11.0	10.2	10.1	11.3	--	--
TMA-P4	12.1	10.9	10.6	10.3	9.5	10.6	11.2	--	11.2
TMA-Surface	12.1	11.2	11.2	11.0	11.5	11.6	11.6	--	11.5
TM1-P1	11.6	10.4	9.8	8.6	7.4	7.6	7.2	--	9.8
TM1-P2	11.4	10.1	9.2	9.2	9.0	9.6	10.1	--	10.8
TM1-P3	11.7	10.7	10.2	9.9	7.4	8.6	9.0	--	8.6
TM1-P4	11.5	10.7	10.1	9.4	9.1	10.1	9.0	--	10.7
TM1-Surface	12.4	11.2	10.8	11.0	11.2	10.7	12.0	--	11.8
R1-P1	12.2	10.7	10.4	10.4	10.2	10.8	10.4	10.9	11.4
R1-P2	11.8	10.9	10.4	10.2	11.3	10.0	11.4	10.7	11.5
R1-P3	11.6	10.9	10.2	9.8	10.6	10.2	10.6	10.4	11.4
R1-P4	11.7	10.6	10.3	10.1	10.0	10.2	11.4	9.7	10.7
R1- Surface	12.2	11.0	10.8	10.8	11.2	11.8	11.6	11.7	11.9
R5-P1	11.9	10.8	10.1	10.7	11.0	10.6	11.2	10.9	11.3
R5-P2	12.1	11.0	10.6	10.8	10.9	10.5	10.7	10.2	10.8
R5-P3	11.8	10.8	10.3	10.8	10.5	10.7	10.6	11.4	12.0
R5-P4	11.8	11.1	10.2	10.7	10.6	10.4	11.0	11.0	10.5
R5-Surface	12.4	11.2	10.9	10.8	11.4	11.6	11.6	11.4	12.2
R10-P1	11.9	11.4	9.4	8.4	8.1	8.8	10.0	7.5	9.6
R10-P2	8.4	11.2	8.4	8.8	10.2	10.7	11.6	10.6	11.0
R10-P3	12.0	11.4	9.1	8.5	8.7	9.5	9.5	8.7	9.3
R10-P4	11.5	9.5	10.0	6.6	5.5	5.5	7.9	6.5	5.9
R10- Surface	12.0	11.6	11.0	11.0	11.2	11.8	12.1	10.9	11.0
R12-P1	11.7	10.7	10.2	10.0	10.2	11.1	11.6	10.4	11.3
R12-P2	3.0	4.2	7.2	7.6	7.2	6.9	7.9	5.9	7.1
R12-P3	11.2	9.4	8.4	--	--	--	--	--	--
R12-P4	5.9	--	--	--	--	--	--	--	--
R12-Surface	11.9	11.0	10.8	10.7	11.5	11.8	11.9	10.7	11.9

Table 6. Intragravel and surface dissolved oxygen concentrations in ppm (Continued)

Site	18-23 Oct	27 Oct 1 Nov	5-10 Nov	13-18 Nov	26-28 Nov	4-6 Dec	14-19 Dec	26 Jan	6-9 Feb
R12A-P1	12.1	10.8	10.4	10.5	9.8	10.3	10.7	--	11.1
R12A-P2	12.0	9.4	10.7	10.6	9.4	10.4	11.2	--	11.0
R12A-P3	11.9	10.5	10.5	10.5	9.7	10.7	10.7	--	11.0
R12A-P4	12.1	11.0	10.6	10.6	10.2	11.1	11.1	--	11.3
R12A-Surface	12.1	11.2	10.7	10.8	11.3	11.7	11.3	--	11.7
R12B-P1	11.0	10.8	10.9	10.0	9.7	11.0	11.0	--	11.2
R12B-P2	10.5	11.2	11.0	10.2	9.3	10.2	10.7	--	11.6
R12B-P3	10.5	11.4	11.0	10.5	9.0	10.2	11.1	--	11.8
R12B-P4	10.6	11.4	10.6	9.8	10.2	11.0	10.8	--	11.8
R12B-Surface	10.9	11.7	11.0	10.7	11.0	11.6	11.4	--	12.0
R13-P1	10.9	10.5	10.5	10.0	9.8	11.0	10.8	--	11.2
R13-P2	10.5	10.5	11.0	10.7	9.8	10.9	11.3	--	11.4
R13-P3	11.0	10.8	10.8	10.6	9.8	11.0	11.0	--	8.8
R13-P4	11.0	10.8	10.7	9.9	10.1	10.4	10.7	--	11.3
R13-Surface	10.9	10.8	11.2	10.7	10.8	11.2	11.6	--	11.6
R14-P1	10.8	10.8	10.7	--	--	--	--	--	--
R14-P2	10.9	10.3	9.7	9.7	11.0	9.9	11.0	--	--
R14-P3	10.8	10.9	10.1	10.5	11.1	10.6	10.7	--	--
R14-P4	10.8	11.0	10.3	10.2	11.1	10.1	10.5	--	--
R14-Surface	11.2	11.2	10.9	10.8	11.2	11.2	11.8	--	--
R14A-P1	11.0	10.8	10.6	10.4	11.0	10.0	10.9	--	--
R14A-P2	11.2	10.9	10.8	10.4	10.8	10.5	11.0	--	--
R14A-P3	11.2	10.9	9.8	--	10.6	10.2	10.8	--	--
R14A-P4	11.1	10.9	10.3	10.0	11.1	10.2	10.2	--	--
R14A-Surface	11.1	11.2	11.2	11.1	11.4	11.3	11.7	--	--
R15-P1	10.8	11.4	10.6	9.8	11.0	10.4	9.4	--	--
R15-P2	10.4	11.8	11.0	10.4	10.7	11.2	10.8	--	--
R15-P3	10.6	11.4	11.0	9.8	10.8	10.2	10.8	--	--
R15-P4	10.6	11.2	10.8	10.1	10.6	10.3	11.1	--	--
R15-Surface	10.8	12.0	11.2	10.8	11.3	10.9	11.5	--	--
R16-P1	10.5	11.5	10.5	10.2	10.5	10.3	10.7	--	--
R16-P2	10.8	11.6	10.6	10.8	11.1	10.1	11.1	--	--
R16-P3	10.8	11.3	10.9	10.2	10.6	10.2	11.4	--	--
R16-P4	10.6	11.5	10.5	10.4	10.9	10.3	11.2	--	--
R16-Surface	11.0	11.9	11.1	10.9	11.2	11.5	11.8	--	--
R19-P1	11.1	11.2	10.3	10.5	10.5	10.9	10.1	--	--
R19-P2	10.1	11.0	9.8	10.0	9.2	9.1	9.3	--	--
R19-P3	11.1	11.7	10.5	10.2	10.4	10.2	10.2	--	--
R19-P4	11.0	11.2	10.2	9.6	--	--	--	--	--
R19-Surface	11.2	11.9	11.2	11.2	11.2	11.6	11.0	--	--

Table 6. Intragravel and surface dissolved oxygen concentrations in ppm (Continued)

Site	18-23 Oct	27 Oct 1 Nov	5-10 Nov	13-18 Nov	26-28 Nov	4-6 Dec	14-19 Dec	26 Jan	6-9 Feb
R19A-P1	11.0	12.0	10.4	10.4	10.1	10.3	11.0	--	--
R19A-P2	10.9	12.0	10.6	10.2	10.1	9.9	10.8	--	--
R19A-P3	11.0	11.9	10.1	10.5	9.9	9.8	11.0	--	--
R19A-P4	10.7	11.8	10.5	10.1	10.2	9.8	11.1	--	--
R19A-Surface	11.0	12.4	11.0	10.8	10.8	11.4	12.0	--	--
R20-P1	10.6	11.6	--	--	--	--	--	--	--
R20-P2	10.5	11.6	9.5	9.2	9.7	9.3	10.3	--	--
R20-P3	10.7	11.8	10.4	9.8	10.1	10.2	11.4	--	--
R20-P4	10.1	11.4	9.8	9.7	9.7	10.0	10.7	--	--
R20-Surface	10.6	12.0	11.0	10.5	11.1	11.1	12.0	--	--
R27-P1	10.7	11.8	9.1	8.4	9.7	9.3	10.2	8.7	9.4
R27-P2	10.6	11.6	10.3	9.8	10.1	9.6	10.1	8.8	9.8
R27-P3	9.1	11.7	5.5	2.6	3.6	3.6	4.4	3.6	8.4
R27-P4	9.1	11.4	8.6	9.4	10.1	8.9	10.2	10.2	10.8
R27-Surface	10.8	12.2	10.9	10.2	11.1	10.5	11.9	11.0	11.4
R28A-P1	10.9	10.6	--	--	--	--	--	--	--
R28A-P2	10.7	10.8	10.0	10.4	10.8	9.2	11.1	10.3	11.0
R28A-P3	11.0	11.0	10.4	10.5	10.4	9.4	11.8	10.6	11.2
R28A-P4	11.0	10.6	9.1	10.4	10.1	9.6	10.1	10.7	10.9
R28A-Surface	11.0	10.8	10.7	10.9	10.9	10.7	11.9	10.8	11.2
R29-P1	11.0	10.6	10.2	9.3	9.9	9.5	11.6	10.1	11.1
R29-P2	11.1	10.7	10.6	9.7	10.2	10.3	11.8	10.3	11.4
R29-P3	10.8	10.3	10.0	9.5	9.2	9.5	11.0	9.2	10.6
R29-P4	11.4	10.3	10.0	9.0	9.1	9.4	10.2	9.7	10.9
R29-Surface	11.3	10.9	11.2	10.3	11.0	10.6	12.1	10.8	11.9
R43-P1	9.6	10.7	10.2	8.7	9.8	10.2	10.1	9.8	11.4
R43-P2	10.1	11.0	10.4	9.1	9.5	9.9	9.6	8.8	11.4
R43-P3	9.4	10.5	10.1	9.2	9.6	10.0	9.6	9.5	11.0
R43-P4	10.0	10.5	10.2	8.9	10.1	8.9	9.7	8.8	11.0
R43-Surface	10.3	11.0	10.8	10.2	10.8	11.0	11.0	10.2	11.8
R57-P1	10.2	10.7	9.8	9.8	10.4	10.6	10.5	10.1	--
R57-P2	10.8	10.9	10.0	10.0	9.6	10.4	10.2	9.8	--
R57-P3	10.8	10.8	9.8	9.6	10.1	10.2	11.0	10.1	--
R57-P4	11.0	11.0	9.7	10.3	9.8	10.1	10.8	10.1	--
R57-Surface	11.0	11.4	10.6	10.5	11.1	11.0	11.5	10.1	--
R58-P1	10.3	10.6	9.9	9.2	9.9	10.2	10.3	8.8	--
R58-P2	9.2	11.0	9.5	9.5	9.4	10.1	10.4	8.9	--
R58-P3	9.4	11.3	9.9	9.6	10.3	10.4	10.6	9.6	--
R58-P4	7.5	6.4	7.2	7.8	7.3	7.5	7.8	7.0	--
R58-Surface	10.2	11.6	10.4	10.5	11.1	11.0	11.1	10.2	--

Table 6. Intragravel and surface dissolved oxygen concentrations in ppm (Continued)

<u>Site</u>	<u>18-23 Oct</u>	<u>27 Oct 1 Nov</u>	<u>5-10 Nov</u>	<u>13-18 Nov</u>	<u>26-28 Nov</u>	<u>4-6 Dec</u>	<u>14-19 Dec</u>	<u>26 Jan</u>	<u>6-9 Feb</u>
R59-P1	9.5	9.7	8.1	8.0	7.7	8.5	8.4	7.0	--
R59-P2	10.6	8.1	7.0	7.1	6.7	7.4	6.9	7.3	--
R59-P3	8.1	8.7	7.6	7.1	7.2	7.7	7.1	7.5	--
R59-P4	9.8	10.3	8.7	8.2	9.1	9.4	8.7	5.9	--
R59-Surface	10.5	11.3	10.6	10.4	10.8	11.1	11.2	10.1	—
R76-P1	10.5	10.2	9.5	9.0	10.3	10.1	10.2	--	--
R76-P2	10.6	10.6	10.2	9.6	10.1	9.9	10.3	--	--
R76-P3	10.4	10.2	10.1	9.0	10.1	9.4	10.3	--	--
R76-P4	10.5	10.3	9.0	8.1	9.3	10.0	9.9	--	--
R76-Surface	11.0	11.0	10.8	11.0	10.8	11.4	11.9	--	--
R78-P1	9.6	9.5	9.1	8.6	9.5	9.7	9.6	--	--
R78-P2	10.2	10.5	10.4	9.7	10.7	10.0	10.0	--	--
R78-P3	10.8	10.3	10.5	9.2	10.3	10.0	10.8	9.0	--
R78-P4	10.4	10.1	10.4	10.0	10.4	10.5	10.6	--	--
R78-Surface	10.8	11.1	11.0	10.6	10.8	11.4	11.6	9.8	--

Table 7. Vertical hydraulic gradient (VHG) at piezometers (P) at 18 project riffles and seven control riffles in the Stanislaus River between Goodwin Dam and Oakdale during eight surveys between October 1999 and February 2000. Measurements during the 18-23 October survey were typically made about 10 to 30 minutes after the piezometers were installed. Measurements during the 6-9 February 2000 survey were made following high flows from storm runoff. The percentage of measurements with positive and negative VHG and the maximum and minimum readings are presented separately for the project and control riffles at the end of this table.

<u>Site</u>	<u>18-23 Oct</u>	<u>27 Oct - 1 Nov</u>	<u>5-10 Nov</u>	<u>13-18 Nov</u>	<u>26-28 Nov</u>	<u>4-6 Dec</u>	<u>14-19 Dec</u>	<u>6-9 Feb</u>
DFG2-P1	--	0.000	0.000	0.013	0.000	--	--	--
DFG2-P2	--	0.000	-0.033	--	--	--	--	--
DFG2-P3	--	--	--	--	--	--	--	--
DFG2-P4	--	0.000	0.007	0.000	--	--	--	--
TMA-P1	-0.033	-0.013	-0.016	0.000	0.000	0.003	0.003	0.000
TMA-P2	-0.033	-0.016	-0.033	0.010	-0.020	0.007	0.016	--
TMA-P3	0.121	-0.033	-0.033	0.000	-0.016	-0.003	0.000	--
TMA-P4	0.066	-0.033	0.000	-0.039	0.007	-0.007	0.007	-0.016
TM1-P1	0.000	-0.016	-0.020	0.000	-0.003	0.000	0.003	0.003
TM1-P2	-0.049	0.000	-0.007	-0.033	0.000	-0.003	-0.003	-0.026
TM1-P3	-0.033	0.000	-0.033	0.007	0.007	0.000	0.000	0.007
TM1-P4	0.000	0.052	-0.033	0.000	0.000	0.000	0.000	0.000
R1-P1	--	0.000	-0.007	0.003	0.000	0.007	0.000	-0.003
R1-P2	--	0.000	0.000	0.000	0.007	0.000	0.049	0.023
R1-P3	--	-0.016	0.016	0.007	-0.016	-0.010	-0.003	-0.013
R1-P4	--	0.000	0.000	0.003	0.000	-0.003	0.000	0.000
R5-P1	--	-0.049	-0.049	-0.033	-0.033	0.000	0.000	0.003
R5-P2	--	-0.049	-0.066	0.000	-0.046	-0.049	-0.033	0.025
R5-P3	--	0.000	-0.007	-0.039	-0.007	0.000	-0.016	-0.007
R5-P4	--	-0.115	-0.016	-0.007	0.000	0.007	0.000	-0.010
R10-P1	--	0.010	0.000	-0.003	0.000	0.000	-0.007	0.049
R10-P2	--	0.000	0.000	-0.007	0.049	0.013	-0.003	0.016
R10-P3	--	0.046	0.000	0.013	0.007	0.003	0.000	0.026
R10-P4	--	-0.016	0.000	0.000	0.003	0.000	0.007	-0.007
R12-P1	--	0.066	0.066	0.020	0.010	0.010	0.052	0.000
R12-P2	--	0.000	-0.033	0.000	-0.013	0.000	-0.033	0.007
R12-P3	--	0.016	-0.033	--	--	--	--	--
R12-P4	--	--	--	--	--	--	--	--
R12A-P1	0.033	-0.013	0.000	0.000	0.007	0.000	0.000	-0.003
R12A-P2	0.039	0.000	0.000	0.000	0.003	0.003	0.066	0.007
R12A-P3	0.000	0.000	-0.016	0.000	0.007	0.010	0.007	0.007
R12A-P4	0.026	0.000	0.000	0.007	0.000	0.000	0.033	0.007

Table 7. Vertical hydraulic gradient (VHG) at the piezometers (Continued).

<u>Site</u>	<u>27 Oct -</u>							
	<u>18-23 Oct</u>	<u>1 Nov</u>	<u>5-10 Nov</u>	<u>13-18 Nov</u>	<u>26-28 Nov</u>	<u>4-6 Dec</u>	<u>14-19 Dec</u>	<u>6-9 Feb</u>
R12B-P1	0.049	0.016	-0.013	-0.026	0.000	0.000	0.000	-0.016
R12B-P2	0.098	0.000	-0.033	-0.033	0.003	0.000	0.003	0.026
R12B-P3	0.092	0.033	0.007	0.000	0.000	-0.003	0.000	-0.016
R12B-P4	0.033	0.033	0.033	-0.033	0.000	-0.007	0.000	0.033
R13-P1	0.082	0.049	-0.026	0.007	-0.033	0.000	-0.007	0.000
R13-P2	0.016	0.033	-0.016	-0.049	0.000	-0.003	0.000	0.066
R13-P3	0.079	0.033	0.000	-0.033	0.000	0.000	0.007	-0.007
R13-P4	0.066	0.000	0.016	0.000	0.000	0.007	0.000	0.016
R14-P1	0.069	-0.039	0.033	--	--	--	--	--
R14-P2	0.033	0.000	0.000	0.026	0.013	0.013	0.003	--
R14-P3	0.138	-0.016	0.000	0.016	0.007	0.003	0.000	--
R14-P4	0.082	-0.013	0.066	0.033	0.000	0.000	0.003	--
R14A-P1	0.000	0.016	0.000	0.020	0.000	0.013	0.000	--
R14A-P2	0.049	0.007	0.000	0.000	0.000	0.007	-0.007	--
R14A-P3	0.125	-0.013	-0.007	--	0.000	0.013	0.131	--
R14A-P4	0.157	0.000	0.007	0.007	0.000	0.000	-0.003	--
R15-P1	0.039	0.013	0.007	0.013	0.000	0.000	0.003	--
R15-P2	0.039	0.000	0.000	0.000	0.003	0.003	0.000	--
R15-P3	0.072	0.016	0.020	0.000	0.003	0.000	0.003	--
R15-P4	0.026	0.007	0.000	0.000	-0.013	0.000	0.003	--
R16-P1	0.003	0.049	0.013	0.007	0.000	0.003	0.000	--
R16-P2	0.000	0.066	0.007	0.007	0.003	0.003	0.000	--
R16-P3	0.085	0.033	-0.033	0.033	0.013	0.000	-0.013	--
R16-P4	-0.016	0.000	0.000	0.000	0.003	0.007	-0.007	--
R19-P1	0.069	0.016	0.000	-0.016	0.007	0.003	-0.013	--
R19-P2	0.105	0.000	0.000	0.000	0.016	-0.007	0.000	--
R19-P3	0.000	0.000	-0.033	-0.007	0.000	0.000	0.007	--
R19-P4	0.085	0.000	-0.033	-0.013	--	--	-0.007	--
R19A-P1	0.085	-0.020	0.000	-0.049	0.000	0.003	0.000	--
R19A-P2	0.069	0.000	-0.016	-0.026	0.003	0.000	-0.007	--
R19A-P3	0.115	-0.033	0.000	0.000	0.007	0.003	0.000	--
R19A-P4	0.098	-0.033	-0.033	0.013	0.000	0.007	0.364	--
R20-P1	0.016	-0.013	--	--	--	--	--	--
R20-P2	0.010	0.000	-0.033	-0.007	0.016	0.000	-0.016	--
R20-P3	0.000	0.000	-0.007	-0.033	-0.033	-0.007	-0.049	--
R20-P4	0.135	-0.016	-0.039	-0.007	-0.039	0.000	0.000	--
R27-P1	0.098	-0.007	-0.033	0.000	0.000	-0.013	-0.016	--
R27-P2	0.013	0.066	-0.020	-0.010	-0.003	-0.003	0.000	--
R27-P3	0.049	-0.033	0.000	0.039	0.066	0.013	0.000	--
R27-P4	0.000	-0.033	-0.033	-0.016	0.007	0.003	0.000	--

Table 7. Vertical hydraulic gradient (VHG) at the piezometers (Continued).

<u>Site</u>	<u>18-23 Oct</u>	<u>27 Oct - 1 Nov</u>	<u>5-10 Nov</u>	<u>13-18 Nov</u>	<u>26-28 Nov</u>	<u>4-6 Dec</u>	<u>14-19 Dec</u>	<u>6-9 Feb</u>
R28A-P1	0.000	0.000	--	--	--	--	--	--
R28A-P2	0.000	0.003	0.000	-0.007	0.000	0.000	-0.033	-0.016
R28A-P3	0.000	-0.066	-0.013	0.000	0.010	0.007	0.007	-0.016
R28A-P4	-0.033	-0.016	0.000	-0.016	0.000	0.000	0.000	0.010
R29-P1	0.000	0.000	0.000	-0.164	0.000	0.000	-0.013	-0.066
R29-P2	0.033	0.007	0.036	0.000	0.033	0.003	-0.007	-0.010
R29-P3	0.000	0.013	0.049	0.000	0.000	0.000	0.000	-0.033
R29-P4	0.000	-0.046	0.000	-0.046	0.000	0.000	-0.033	-0.025
R43-P1	0.000	0.000	0.000	0.000	-0.007	0.000	0.000	-0.016
R43-P2	0.016	-0.033	-0.013	0.007	-0.013	0.000	0.000	0.016
R43-P3	-0.066	0.033	0.007	0.000	0.000	0.007	0.000	-0.016
R43-P4	0.033	-0.098	0.000	0.000	-0.007	0.000	-0.007	0.000
R57-P1	0.000	0.000	0.013	0.000	-0.003	0.000	0.000	--
R57-P2	-0.016	-0.066	0.000	-0.033	0.000	0.007	0.000	--
R57-P3	0.000	-0.033	-0.052	0.000	0.003	0.000	0.000	--
R57-P4	-0.039	-0.007	0.000	-0.003	-0.013	0.000	-0.007	--
R58-P1	0.007	-0.033	-0.033	-0.049	-0.033	-0.003	-0.016	--
R58-P2	-0.049	-0.049	0.000	0.000	0.000	0.000	-0.013	--
R58-P3	0.000	-0.033	0.007	0.007	0.003	0.000	0.000	--
R58-P4	0.066	0.000	-0.016	0.000	0.000	0.013	0.007	--
R59-P1	-0.033	-0.016	-0.013	-0.003	0.000	-0.003	0.000	--
R59-P2	0.000	-0.016	0.000	0.013	-0.003	0.039	0.000	--
R59-P3	-0.049	-0.016	0.000	0.000	0.000	0.000	-0.007	--
R59-P4	-0.016	-0.033	0.000	0.007	-0.007	0.000	0.007	--
R76-P1	-0.016	0.033	-0.033	-0.033	0.007	0.000	0.000	--
R76-P2	-0.016	0.007	-0.016	-0.016	0.000	0.003	0.000	--
R76-P3	0.000	-0.049	0.000	0.000	0.000	0.000	0.000	--
R76-P4	0.000	0.007	0.000	0.007	-0.003	0.007	-0.007	--
R78-P1	0.000	-0.007	-0.039	-0.013	0.000	0.003	-0.033	--
R78-P2	-0.033	0.016	0.000	-0.049	-0.003	0.000	0.000	--
R78-P3	0.066	0.007	0.000	0.013	0.003	0.003	0.033	--
R78-P4	0.016	0.000	-0.033	0.007	-0.010	-0.010	0.007	--

Table 7. Vertical hydraulic gradient (VHG) at the piezometers (Continued).

Project Riffles

	<u>18-23 Oct</u>	<u>27 Oct - 1 Nov</u>	<u>5-10 Nov</u>	<u>13-18 Nov</u>	<u>26-28 Nov</u>	<u>4-6 Dec</u>	<u>14-19 Dec</u>	<u>6-9 Feb</u>
Maximum	0.157	0.066	0.066	0.033	0.033	0.013	0.364	0.066
Minimum	-0.049	-0.115	-0.066	-0.164	-0.046	-0.049	-0.033	-0.066
% Positive	62.9%	28.6%	21.7%	29.9%	32.8%	38.8%	30.9%	38.7%
% Negative	12.9%	38.6%	37.7%	34.3%	22.4%	16.4%	27.9%	51.8%

Control Riffles

Maximum	0.135	0.066	0.066	0.039	0.066	0.039	0.052	0.066
Minimum	-0.066	-0.098	-0.039	-0.033	-0.039	-0.013	-0.049	-0.026
% Positive	31.8%	34.5%	7.1%	25.9%	33.3%	33.3%	14.8%	43.8%
% Negative	36.4%	44.8%	53.6%	40.7%	33.3%	18.5%	37.0%	18.8%

Table 8. The deviation in intragravel water temperature from surface water temperature, the intragravel D.O. concentration, and the bed permeability during the 14-19 December 1999 survey for the sites where elevated intragravel water temperatures were observed and the mean for all sites.

<u>Site</u>	<u>Temp Deviation (F)</u>	<u>D.O. (ppm)</u>	<u>PERM (cm/hr)</u>
TM1 P4 -Natural	0.2 F & Stable	9.0	759
R10 P1-Natural	0.2 F & Stable	10.0	--
R10 P2 -Natural	Temporary Stable	11.6	--
R10 P3 -Natural	Stable	9.5	--
R10 P4-Natural	1.0 F & Stable	7.9	1,521
R12 P2-Natural	1.0 F & Stable	7.9	4,840
R12 P3-Natural	0.5 F, Temporary Stable	--	--
R43 P4-Natural	Stable	9.7	5,453
R58 P4-Project	5.0 F, Stable	7.8	4,100
R59 P1-Natural	0.8 F, Stable	8.4	4,220
R59 P2-Natural	1.8 F, Stable	6.9	2,490
R59 P3-Natural	13 F, Stable	7.1	1,550
R59 P4-Natural	Stable	8.7	4,630
R78 P1-Project	0.3 F, Stable	11.6	4,790
Mean Project Sites		10.7	87,089
Mean Control Sites		9.3	8,966

APPENDIX 3

Pre- and Post-Project Contour Maps of Study Sites and Redd Locations

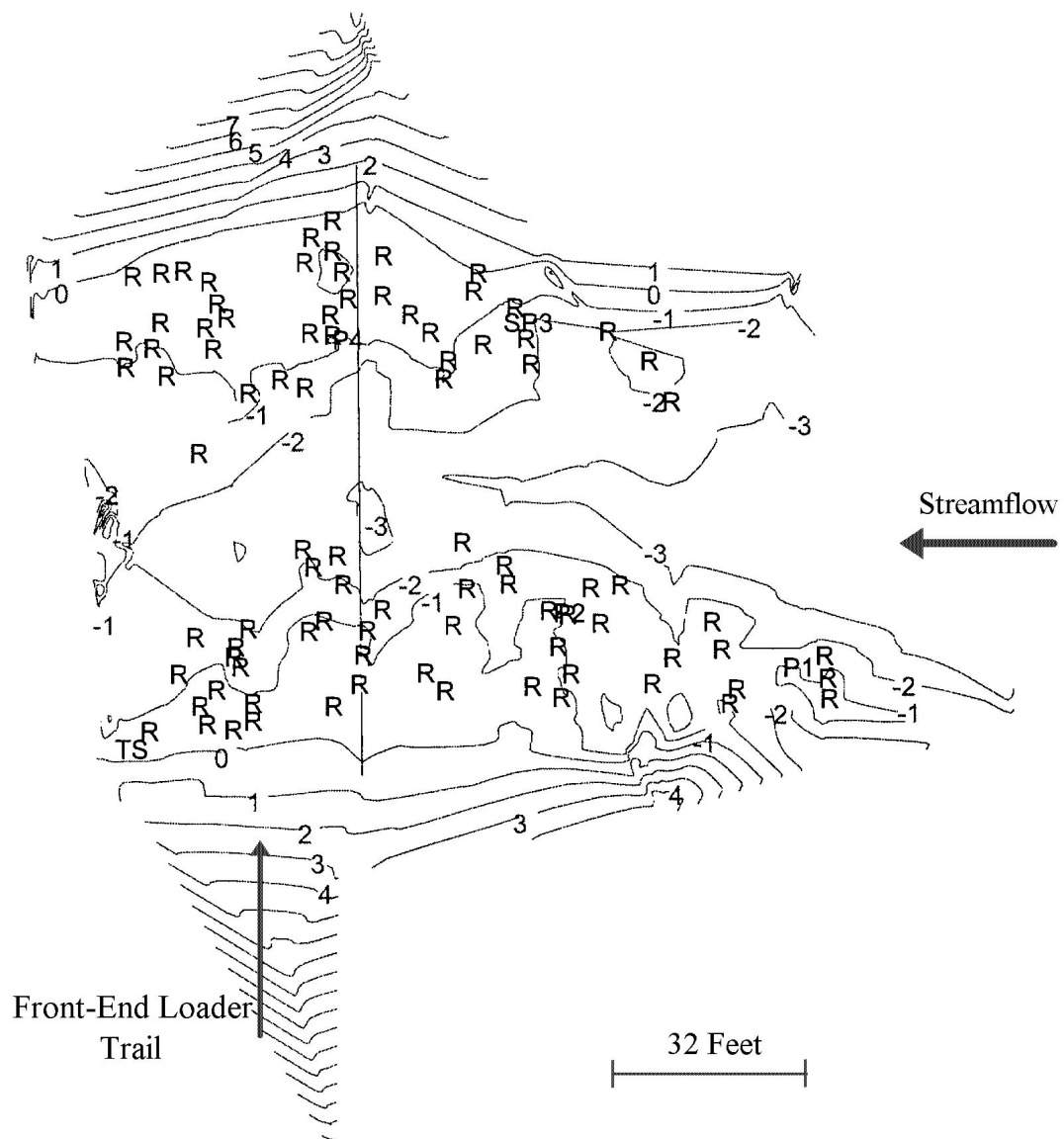


Figure 1. Contour map of Riffle DFG2 at rivermile 58.0 on the Stanislaus River showing streambed elevations measured on 14 December 1999, which was one year after gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), three piezometers (P1, P2, P4), and one standpipe (SP3). The water surface elevation was 0.3325 feet at the transect. The elevation of the top of the transect pin on river left is 5.05 feet.

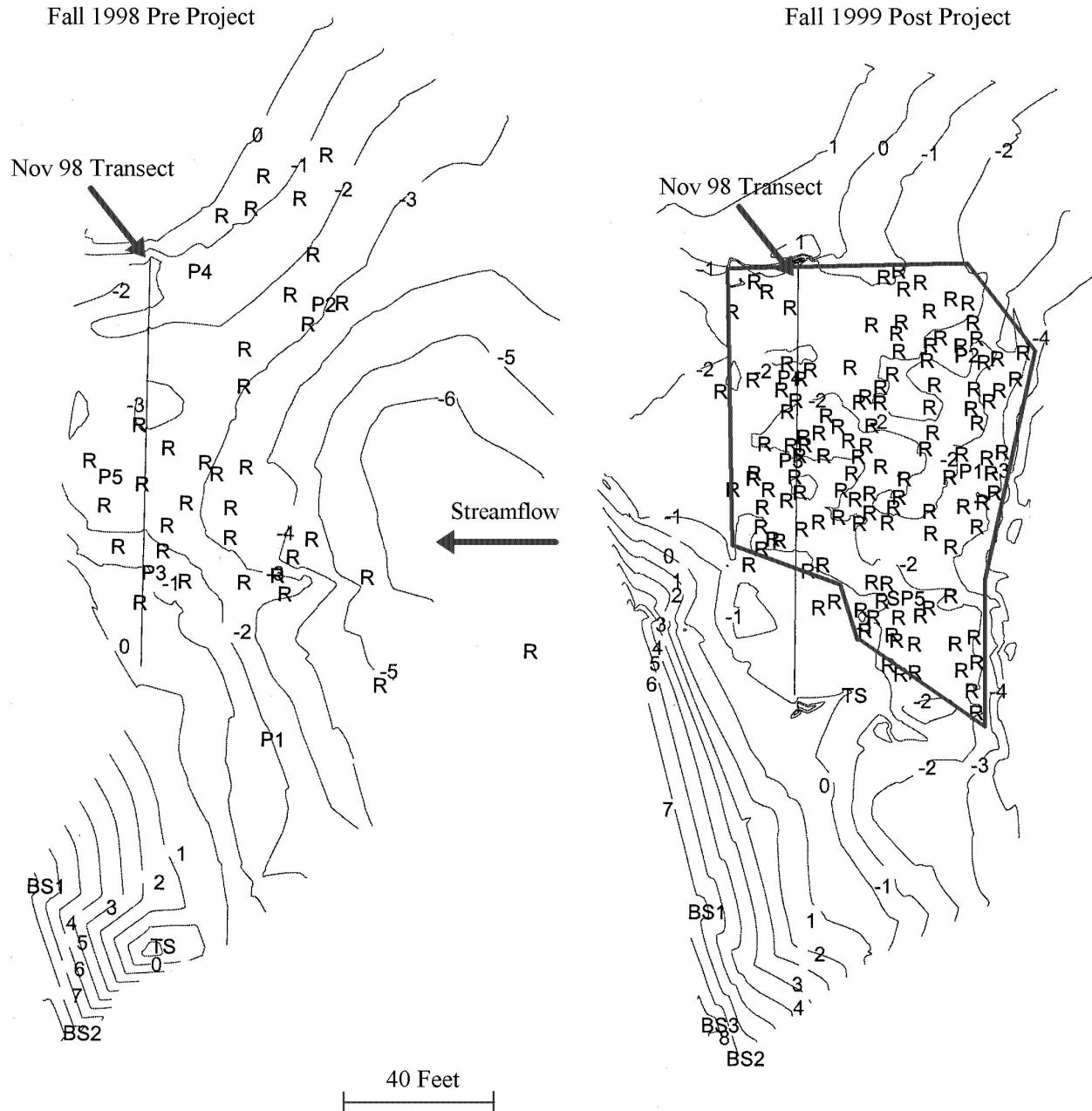


Figure 2 Contour maps of Riffle TMA on the Stanislaus River at rivermile 56.8 showing pre-project streambed elevations measured on 4 August 1999 (left) and post-project elevations measured on 3 December 1999 (right). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (left) and 1999 (right), transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was 0.03 feet in August and -0.395 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 7.56 feet, BS2 is 8.06 feet, and BS3 is 9.425 feet.

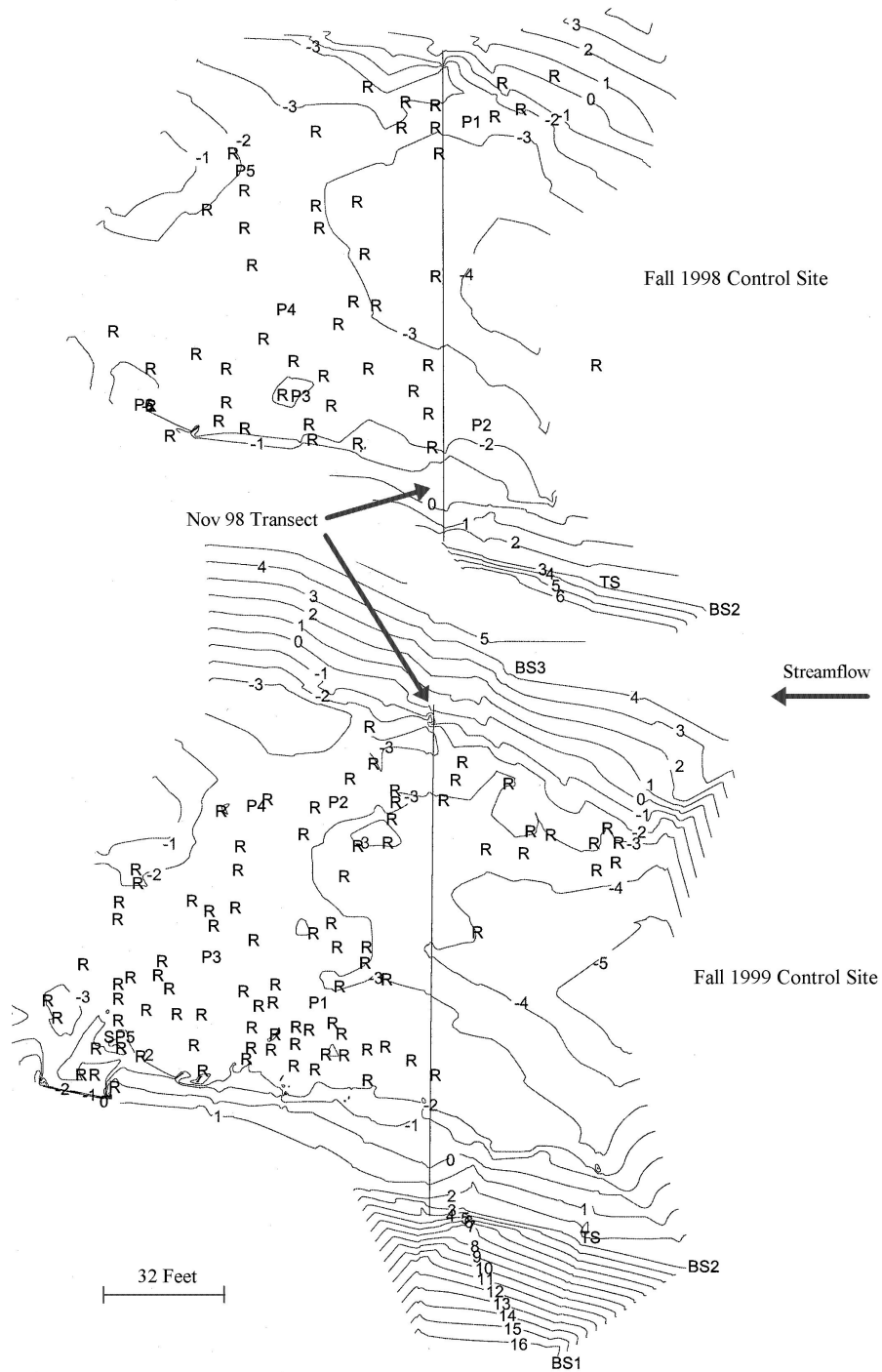


Figure 3. Contour maps of Riffle TM1 at river mile 56.6 on the Stanislaus River showing streambed elevations measured on 24 August 1999 (upper) and 13 December 1999 (lower). The map shows the locations of chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), transects (vertical line), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -0.595 feet in August and -0.98 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 16.51 feet, BS2 is 2.755 feet, and BS3 is 4.72 feet.

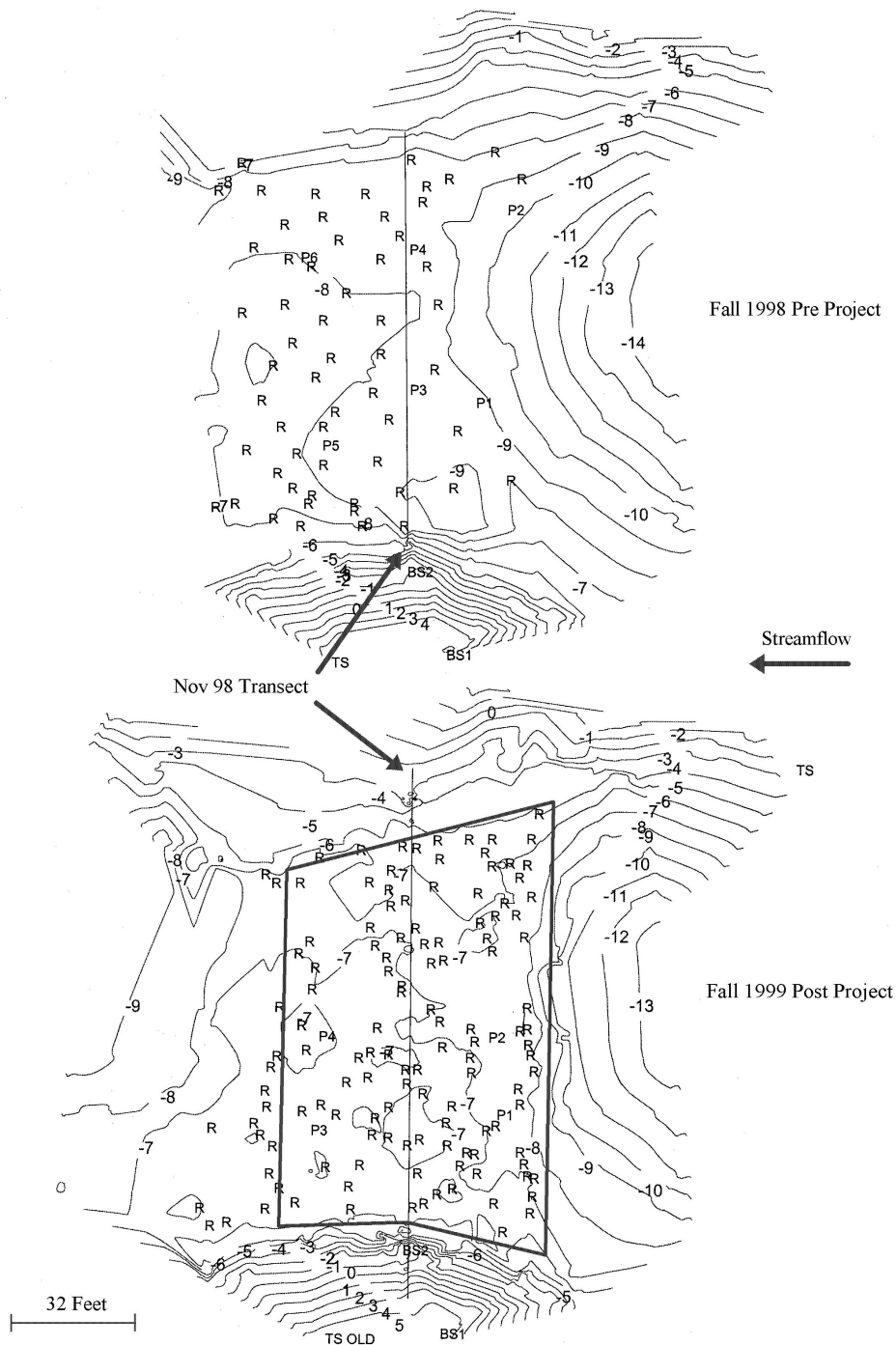


Figure 4. Contour maps of Riffle R1 at river mile 54.55 on the Stanislaus River showing pre-project streambed elevations on 3 August 1999 (upper) and post-project elevations on 14 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 and 1999, the transects (vertical lines), total stations (TS), 1998 standpipes (P) and 1999 piezometers (P). The water surface elevation at the transect was -5.01 feet in August and -5.42 feet in December. The elevation of the marked rock at backsight 1 (BS1) is 5.825 feet, the pin at BS3 is 4.36 feet, and the pin at BS4 is 7.65 feet. BS2 was vandalized.

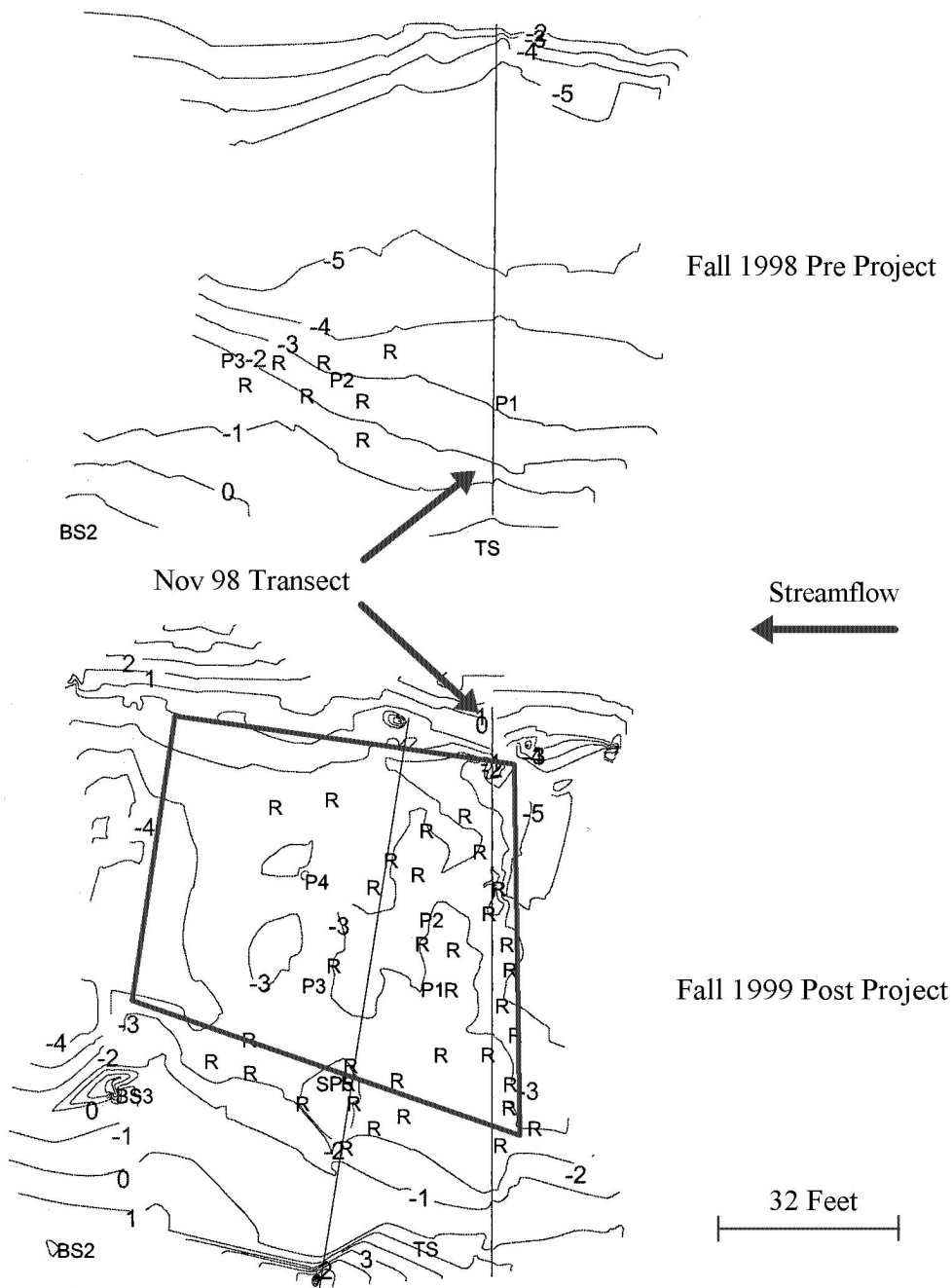


Figure 5. Contour maps of Riffle R5 at river mile 53.9 on the Stanislaus River showing pre-project streambed elevations on 5 August 1999 (upper) and post-project elevations on 15 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -0.88 feet in August and -1.105 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.705 feet, BS2 is 2.145 feet, and BS3 is 2.220 feet.

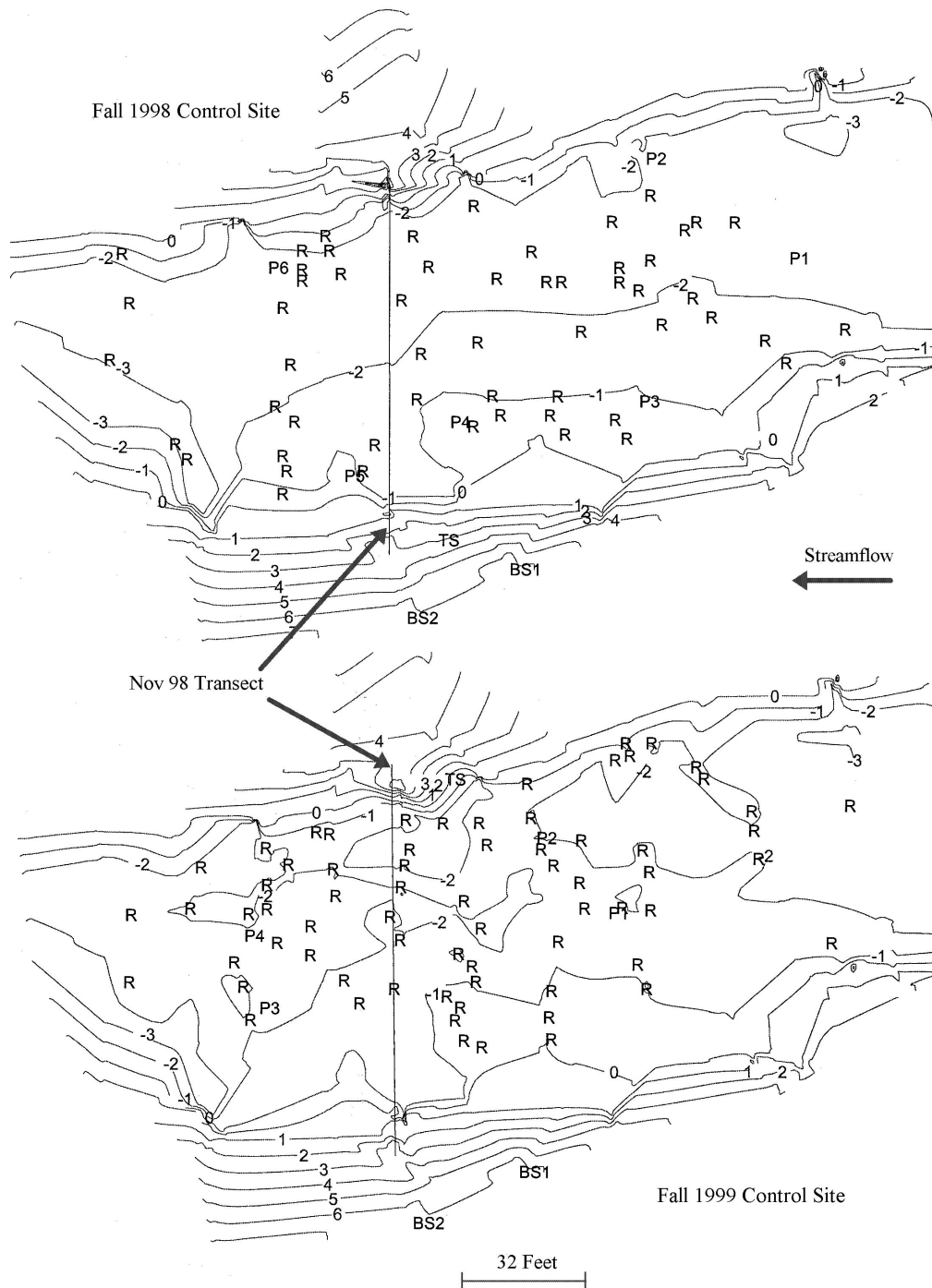


Figure 6. Contour maps of Riffle R10 at river mile 53.5 on the Stanislaus River showing streambed elevations measured on 23 August 1999 (upper) and 15 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1998 (upper) and fall 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was 0.86 feet in August and 0.815 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 6.355 feet, BS2 is 6.44 feet, and BS3 is 14.070 feet.

BS1

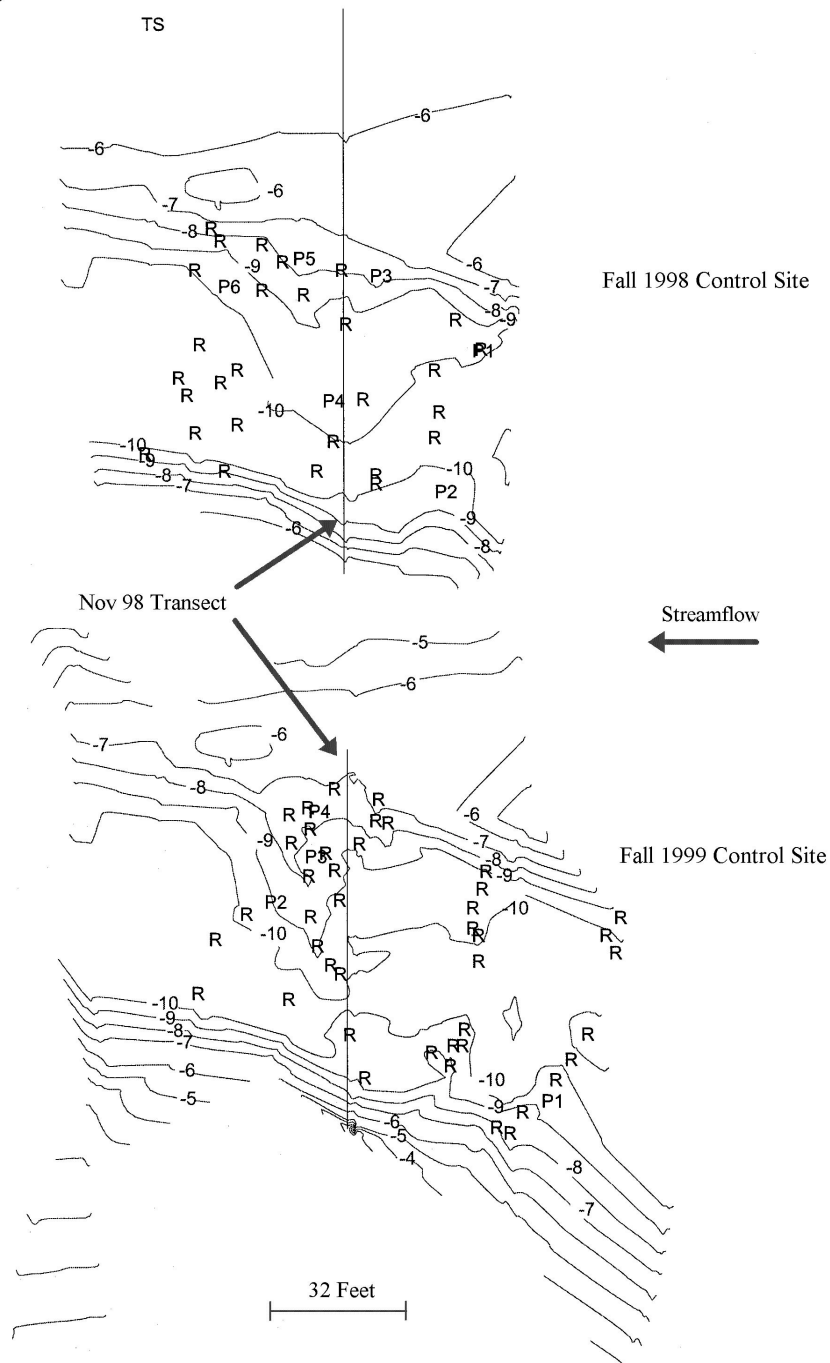


Figure 7. Contour maps of Riffle R12 at river mile 53.3 on the Stanislaus River showing streambed elevations on 23 August 1999 (upper) and 14 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -6.48 feet in August and -6.35 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.785 feet, BS2 is 5.20 feet, and BS3 is -1.415 feet.

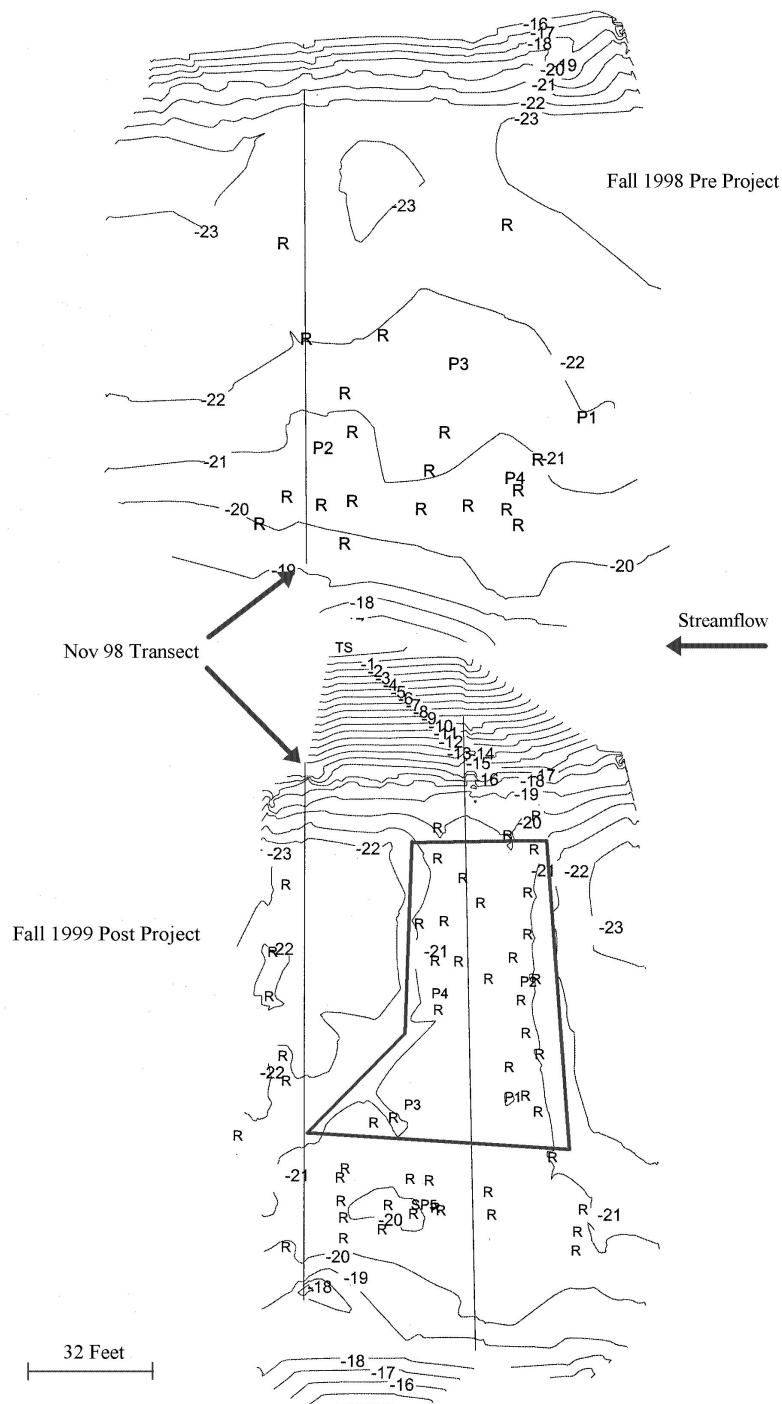


Figure 8. Contour maps of Riffle R12A at river mile 52.82 on the Stanislaus River showing pre-project streambed elevations on 1 August 1999 (upper) and post-project elevations on 12 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -19.38 feet in August and -18.90 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is -0.355 feet and BS2 is 0.975 feet.

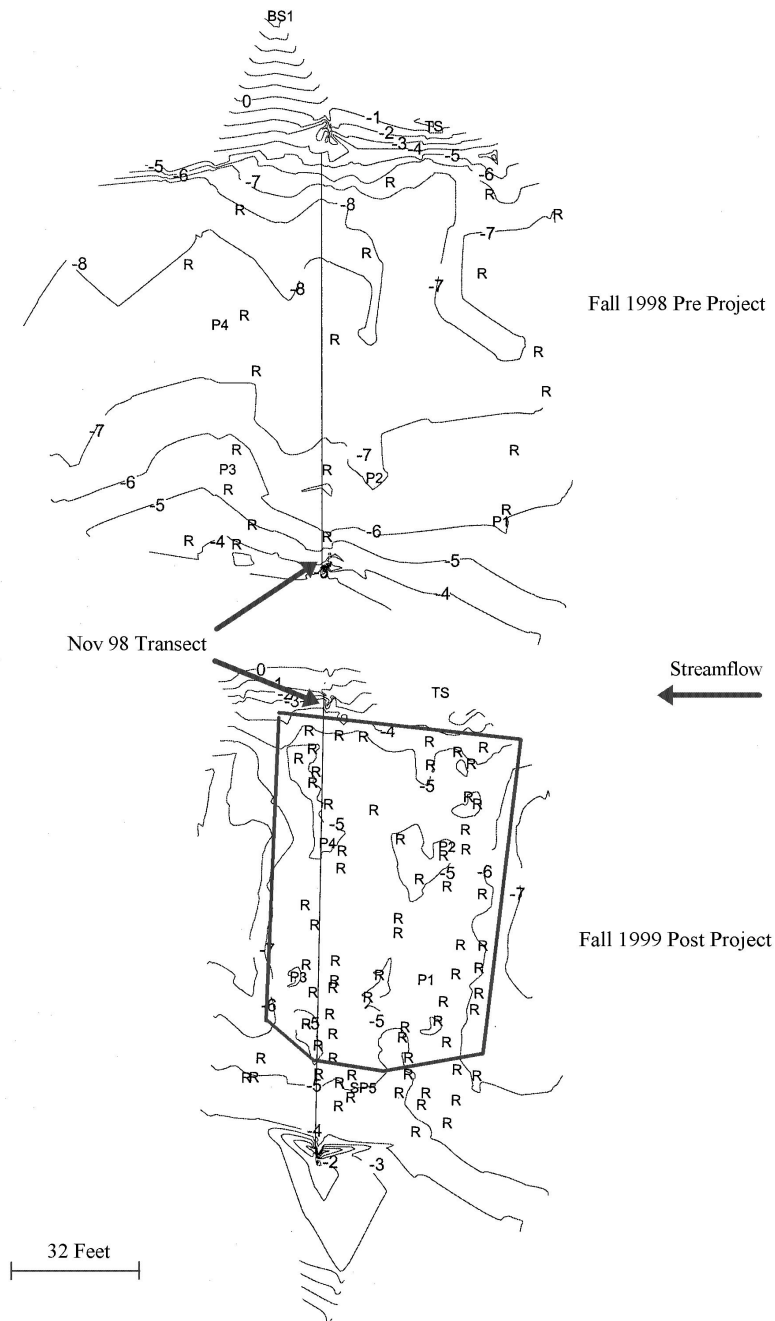


Figure 9. Contour maps of Riffle R12B at river mile 52.77 on the Stanislaus River showing pre-project streambed elevations on 11 August 1999 (upper) and post-project elevations on 12 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -4.215 feet in August and -3.713 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 6.375 feet, BS3 is 8.430 feet, and BS4 is 5.825 feet.

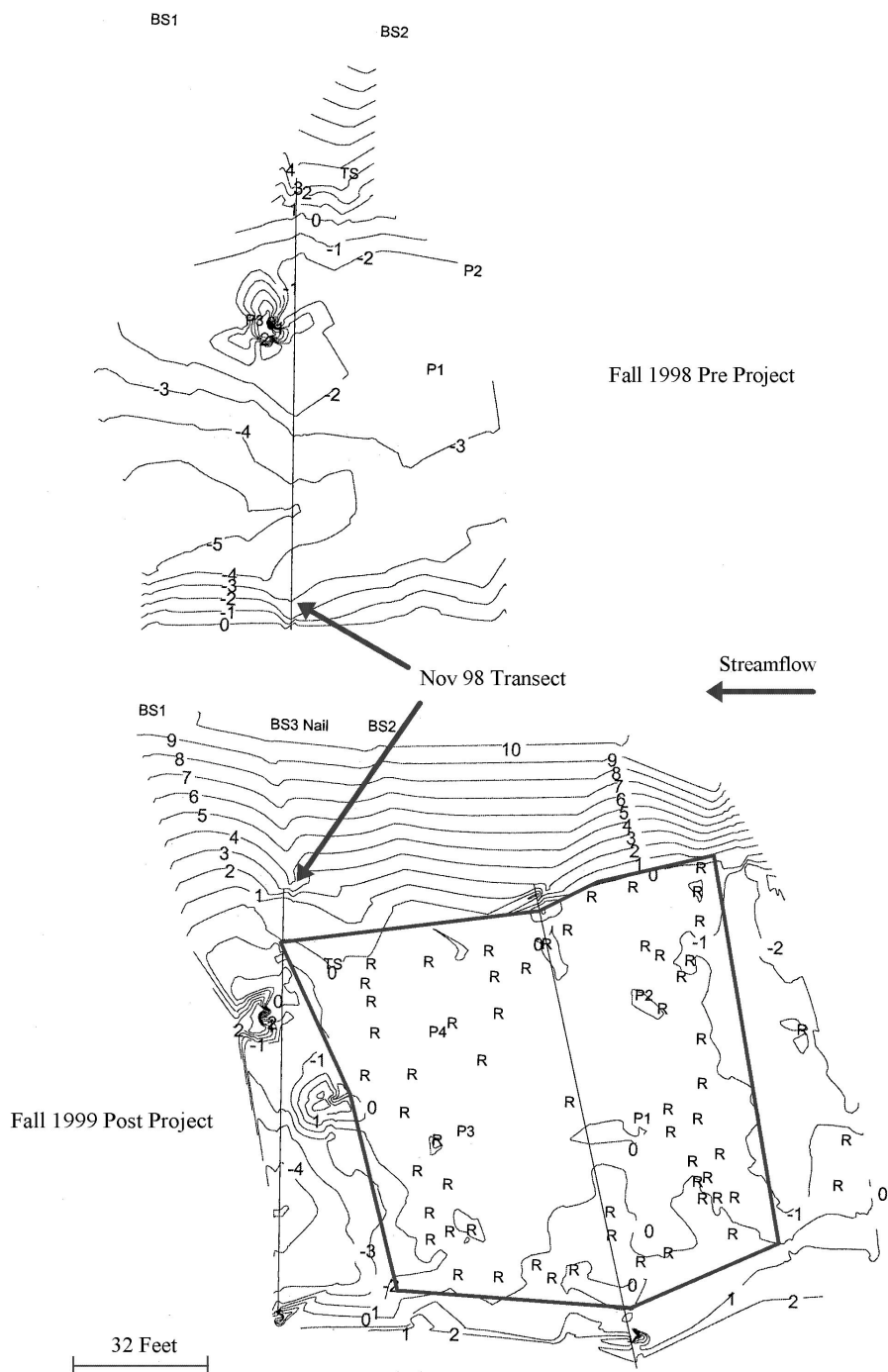


Figure 10. Contour maps of Riffle R13 at river mile 52.73 on the Stanislaus River showing pre-project streambed elevations on 12 August 1999 (upper) and post-project elevations on 12 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was 0.765 feet in August and 1.085 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 9.715 feet, BS2 is 10.89 feet, and the nail at BS3 is 10.335 feet.

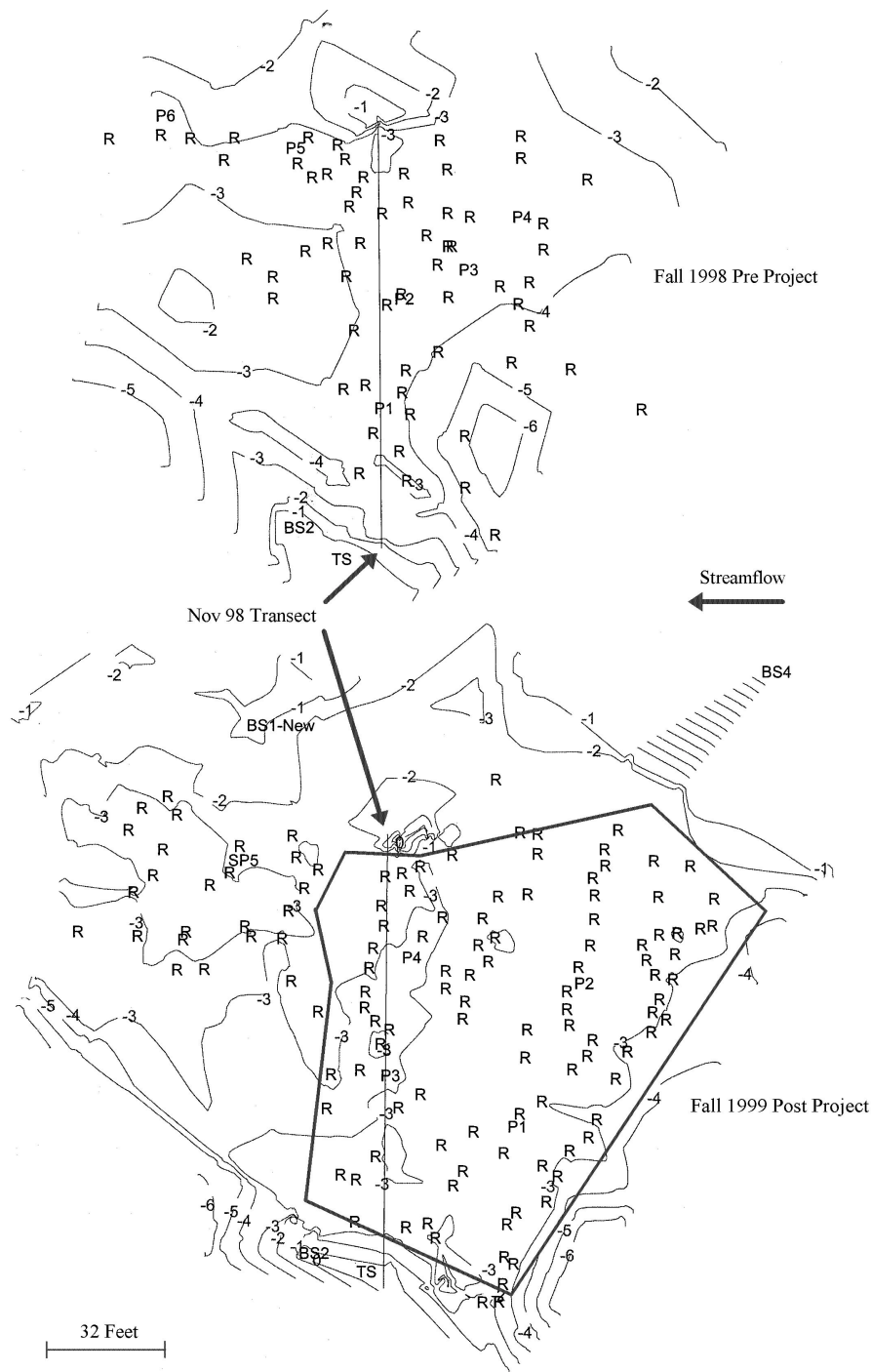


Figure 11. Contour maps of Riffle R14 at river mile 52.6 on the Stanislaus River showing pre-project streambed elevations on 12 August 1999 (upper) and post-project elevations on 11 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -1.615 feet in August and -2.72 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is -0.735 feet, BS2 is 0.53 feet, and BS4 is 12.980 feet.

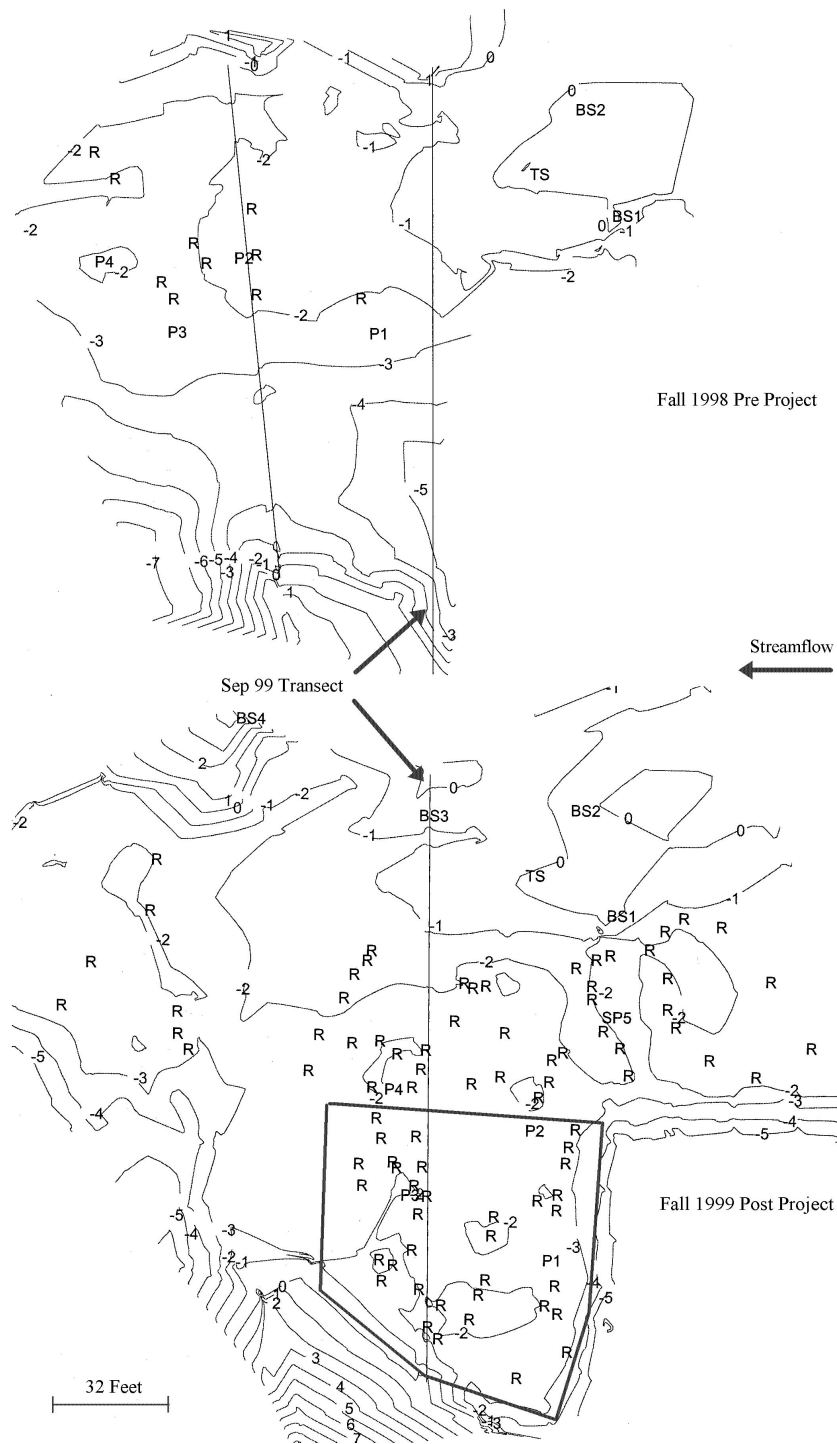


Figure 12. Contour maps of Riffle R14A at river mile 52.57 on the Stanislaus River showing pre-project streambed elevations on 13 August 1999 (upper) and post-project elevations on 11 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -1.265 feet in August and -0.805 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.465 ft, BS2 is 0.56 ft, BS3 is -0.060 ft, and BS4 is 4.410 ft.

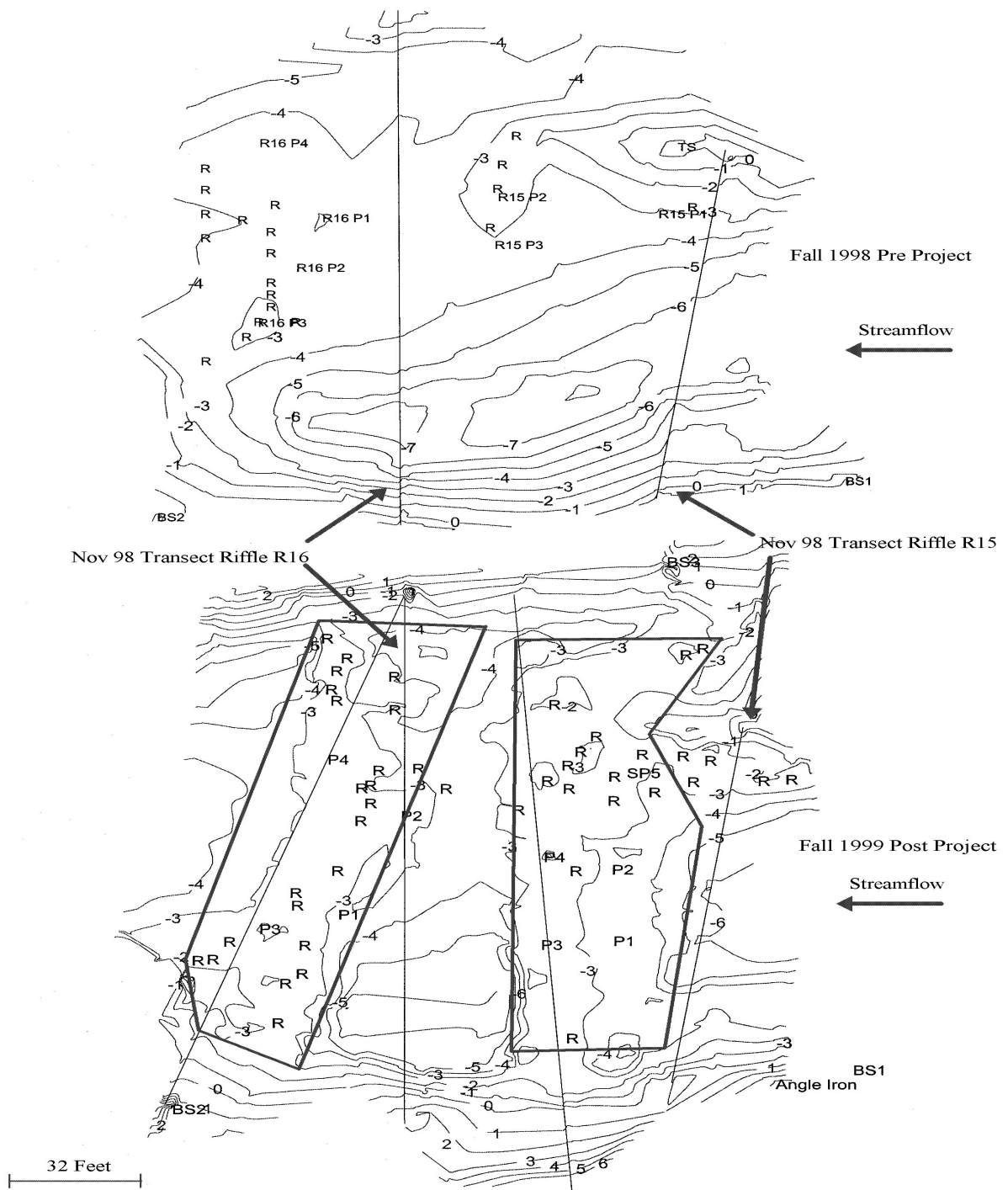


Figure 13. Contour maps of riffles R15 (right) and R16 (left) at rivermile 52.5 on the Stanislaus River showing pre-project streambed elevations on 10 August 1999 (upper) and post-project elevations on 10 December 1999 (lower). The maps show the locations of gravel placement (polygons), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the R15 transect was -0.665 feet in August and -1.038 feet in December and at the R16 transect (left) was -0.735 feet in August and -1.125 feet in December. The elevation of the top of the metal pin at backsight 1 (BS1) is 4.155 feet, BS2 is 1.13 feet, and BS3 is 1.840 feet.

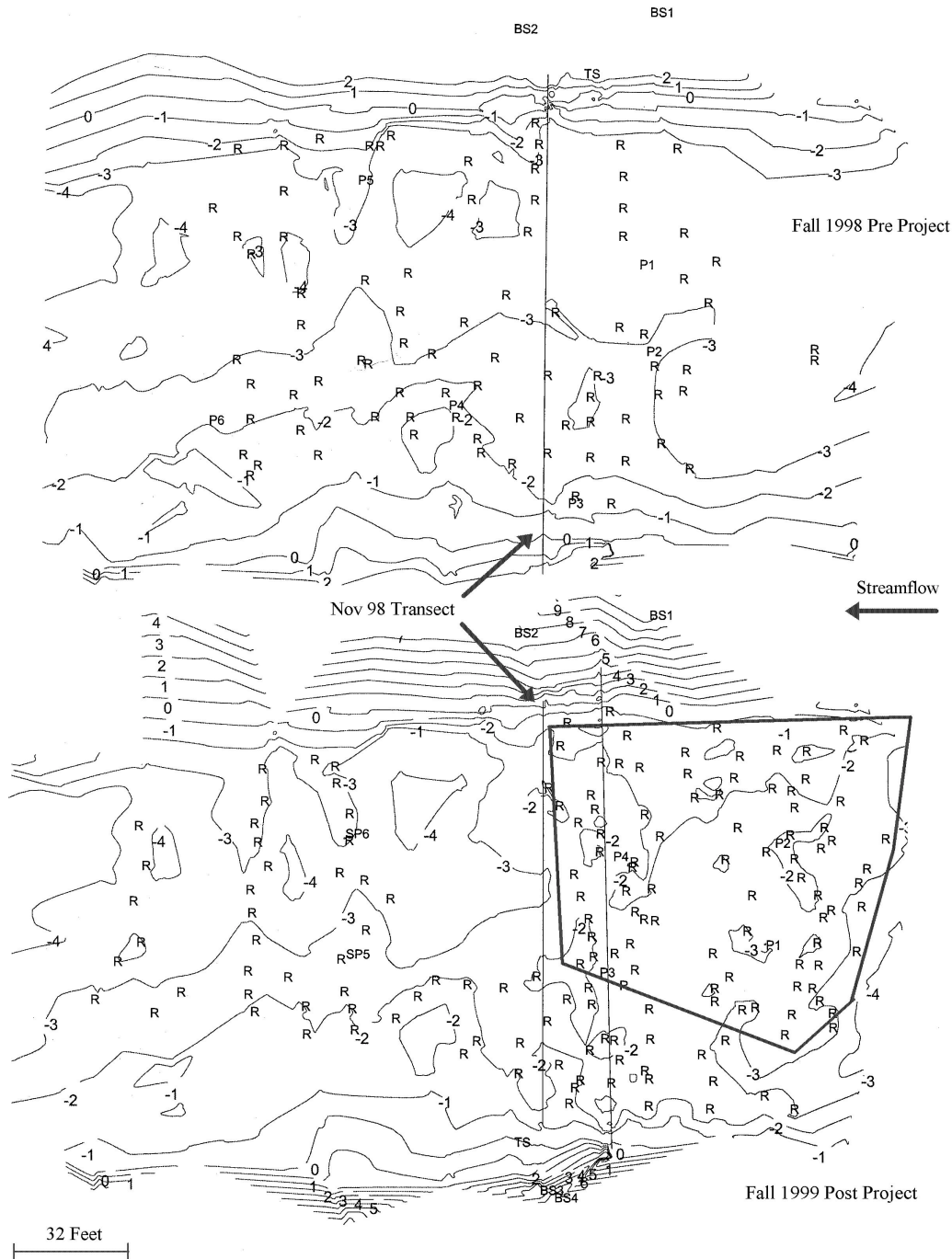


Figure 14. Contour maps of Riffle R19 at rivermile 52.13 on the Stanislaus River showing pre-project streambed elevations on 13 August 1999 (upper) and post-project elevations on 8 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -0.675 feet in August and -0.72 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 9.04 feet, BS2 is 6.755 feet, BS3 is 6.530 feet, and BS4 is 8.665 feet.

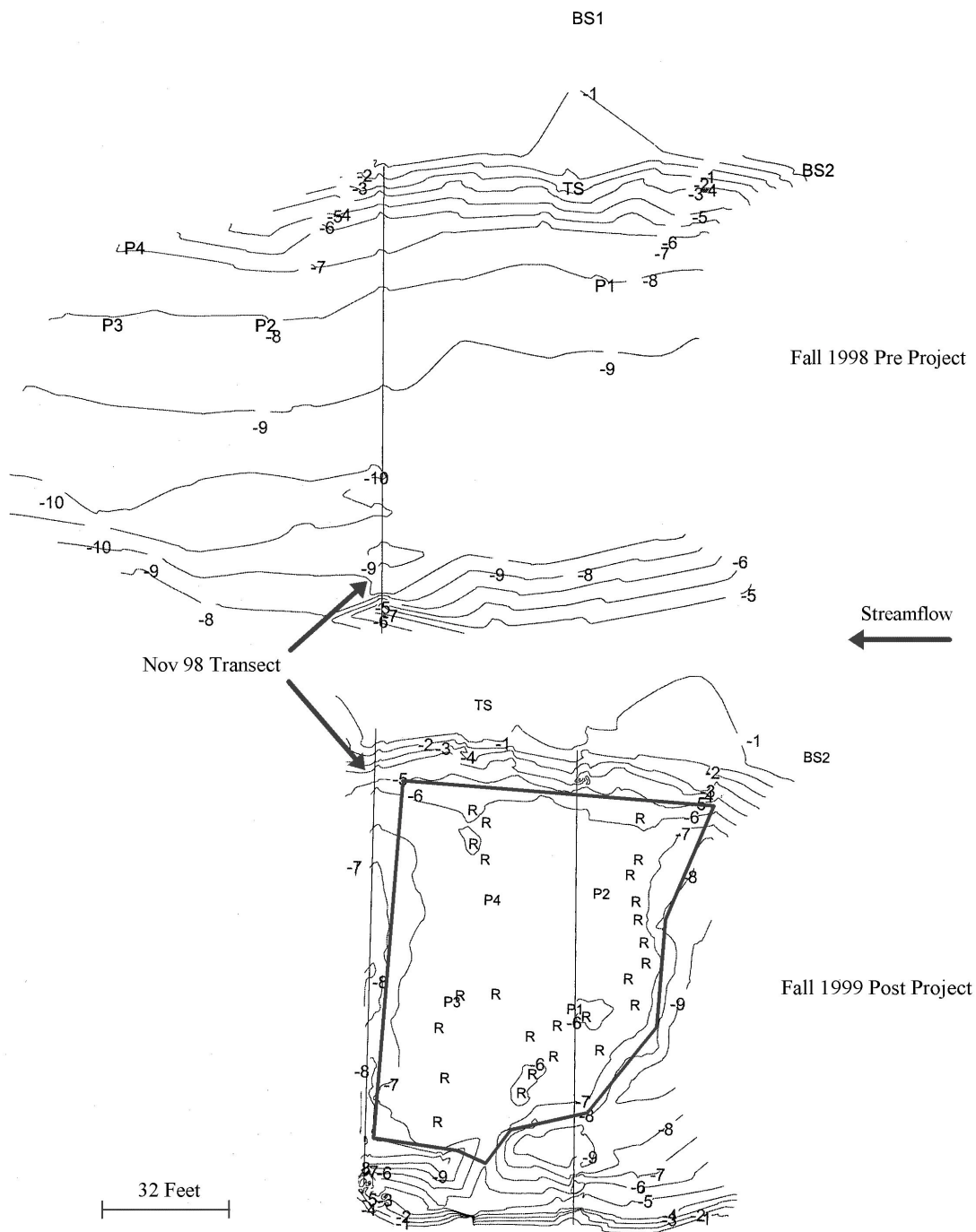


Figure 15. Contour maps of Riffle R19A at river mile 52.06 on the Stanislaus River showing pre-project streambed elevations on 18 August 1999 (upper) and post-project elevations on 8 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999, transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -4.36 feet in August and -4.59 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is -0.125 feet, BS2 is 0.71 feet, and BS3 was 1.180 feet.

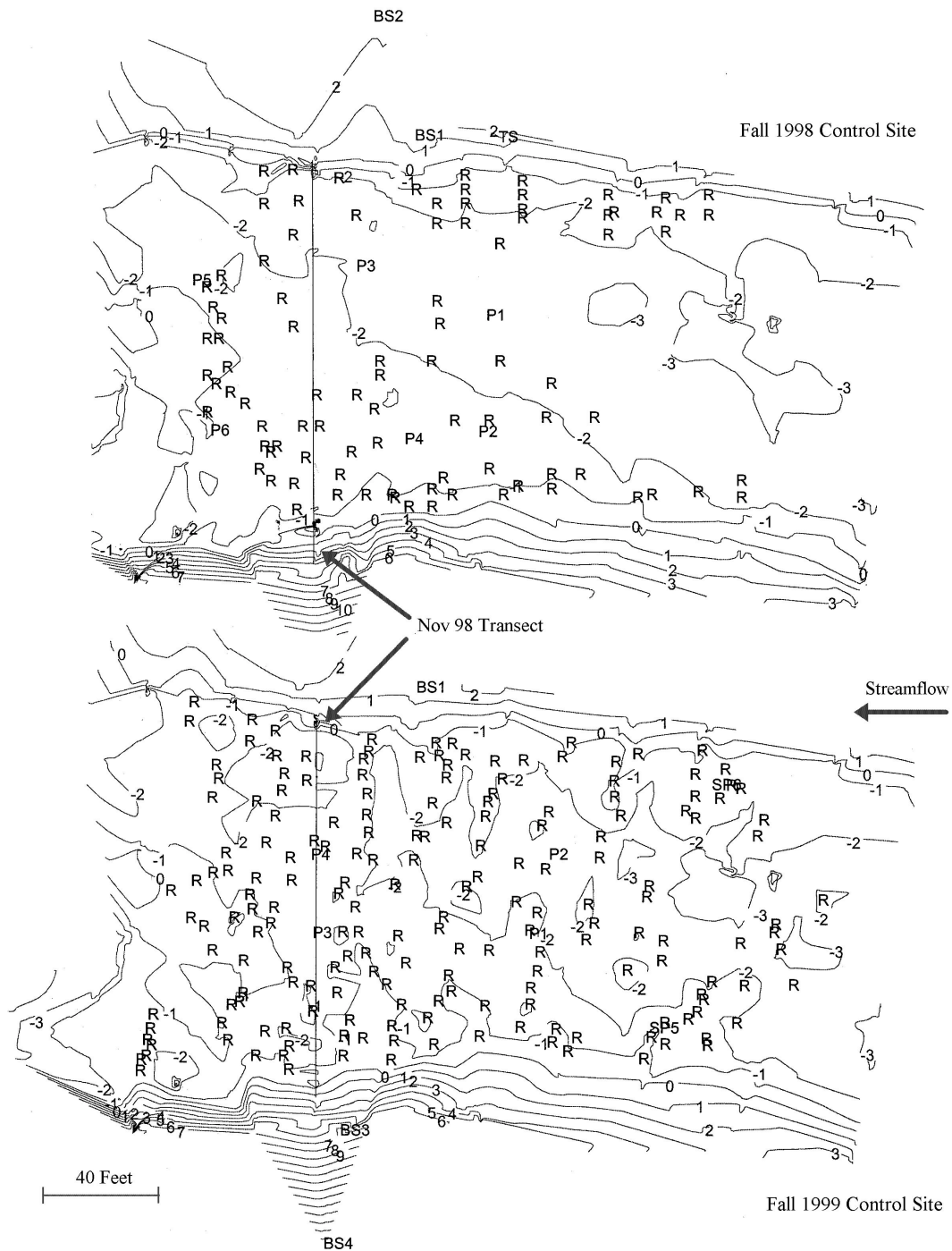


Figure 16. Contour maps of Riffle R20 at river mile 51.8 on the Stanislaus River on 18 August 1999 (upper) and 7 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was 0.19 feet in August and -0.08 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.605 feet, BS2 is 2.121 feet, BS3 is 7.370 feet, and BS4 is 19.505 feet.

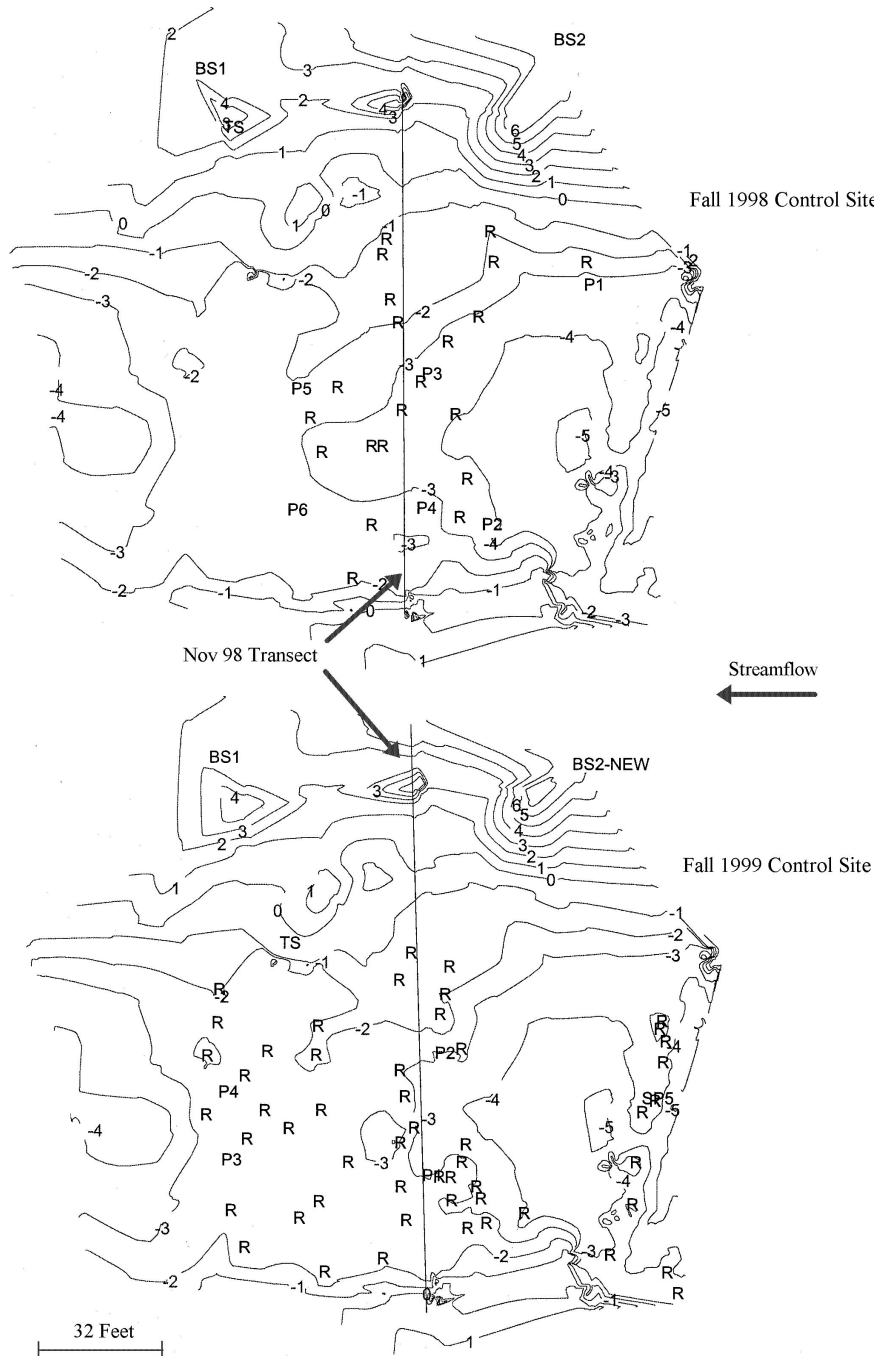


Figure 17. Contour maps of Riffle R27 at rivermile 50.8 on the Stanislaus River showing streambed elevations on 20 August 1999 (upper) and 6 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical line), total stations (TS), 1998 standpipes, and 1999 piezometers (P). The water surface elevation at the transect was -0.54 feet in August and -0.75 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 2.95 feet and BS3 is 6.69 feet.

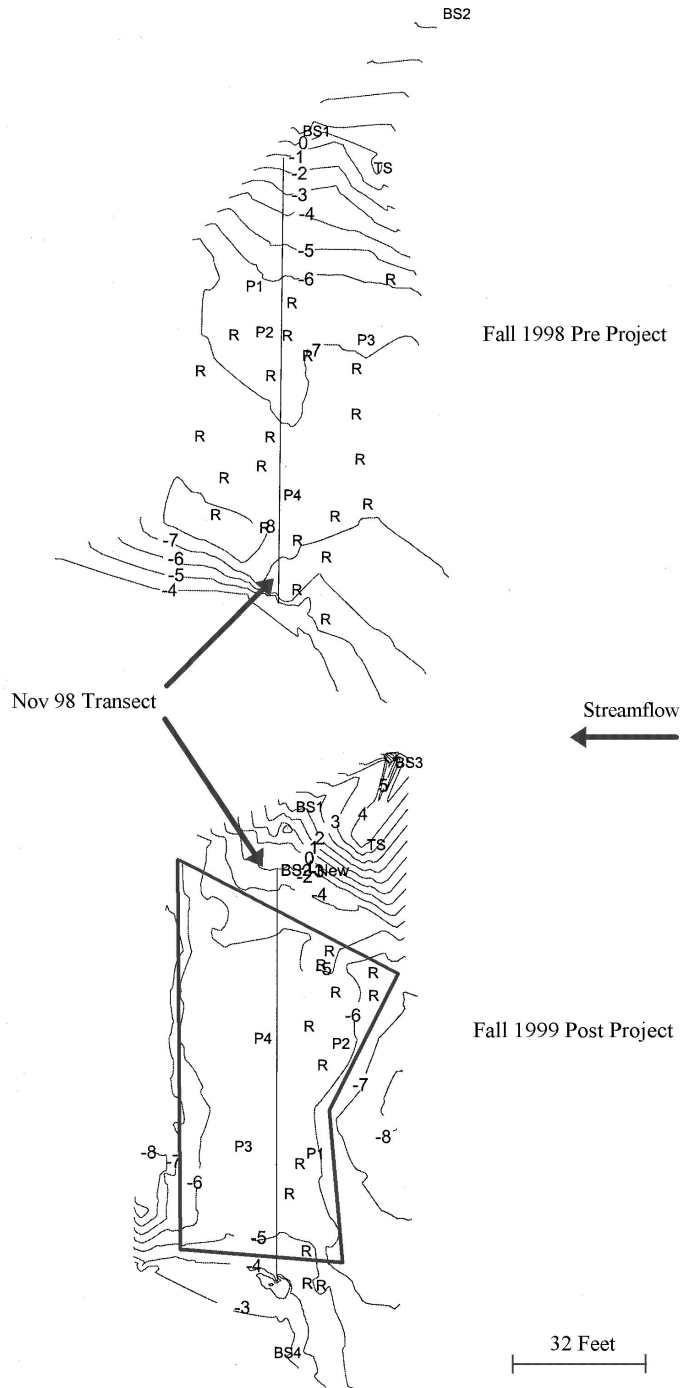


Figure 18. Contour maps of Riffle R28A at river mile 50.2 on the Stanislaus River showing pre-project streambed elevations on 6 August 1999 (upper) and post-project elevations on 6 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -3.90 feet in August and -3.78 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.52 feet, a new BS2 is -2.725 feet, and BS3 is 6.10 feet.

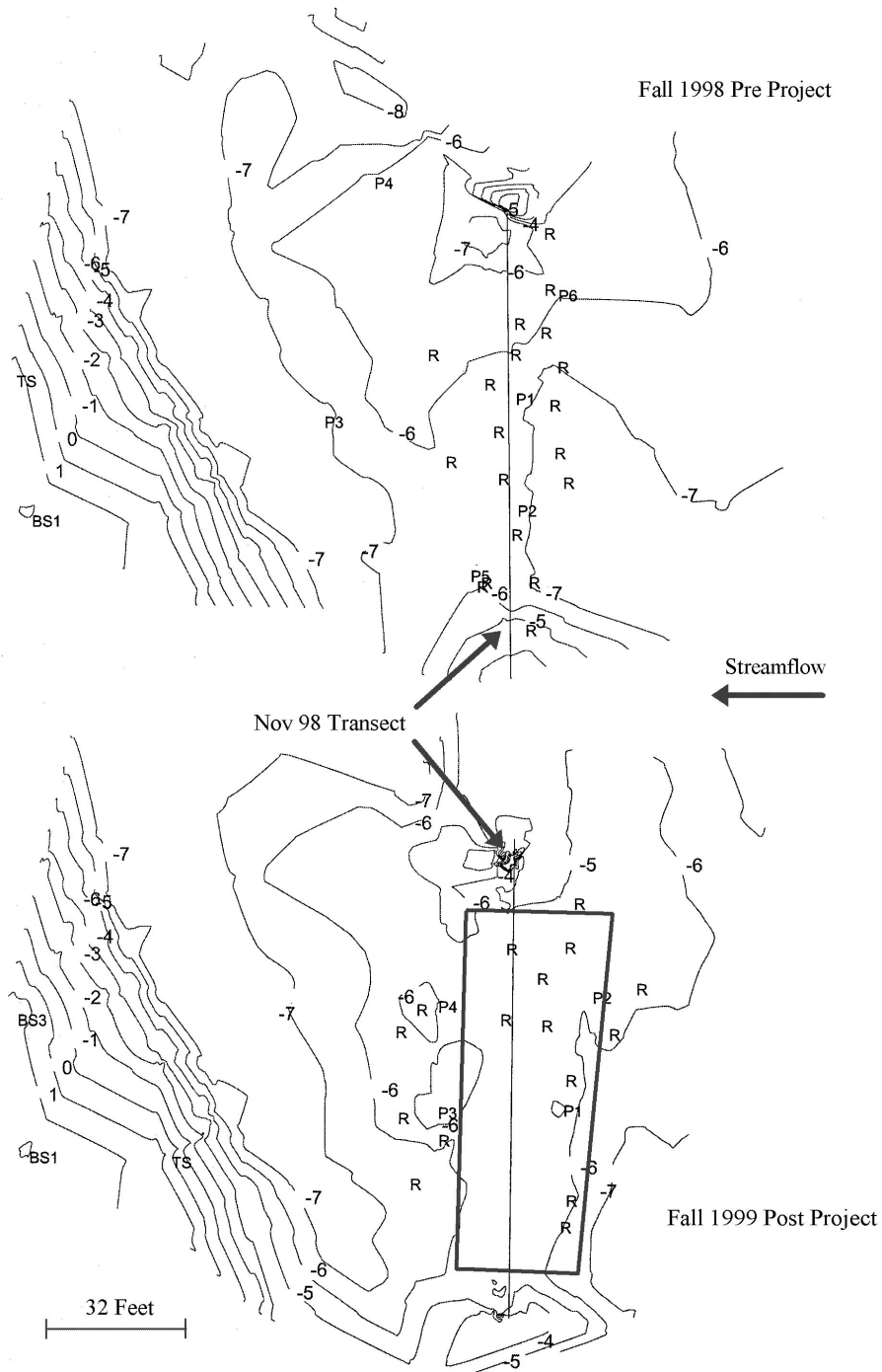


Figure 19. Contour maps of Riffle R29 at rivermile 49.75 on the Stanislaus River showing pre-project streambed elevations on 9 August 1999 (upper) and post-project elevations on 6 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), the transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -4.135 feet in August and -4.56 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.995 feet, BS2 is 1.88 feet, and BS3 is 1.460 feet.

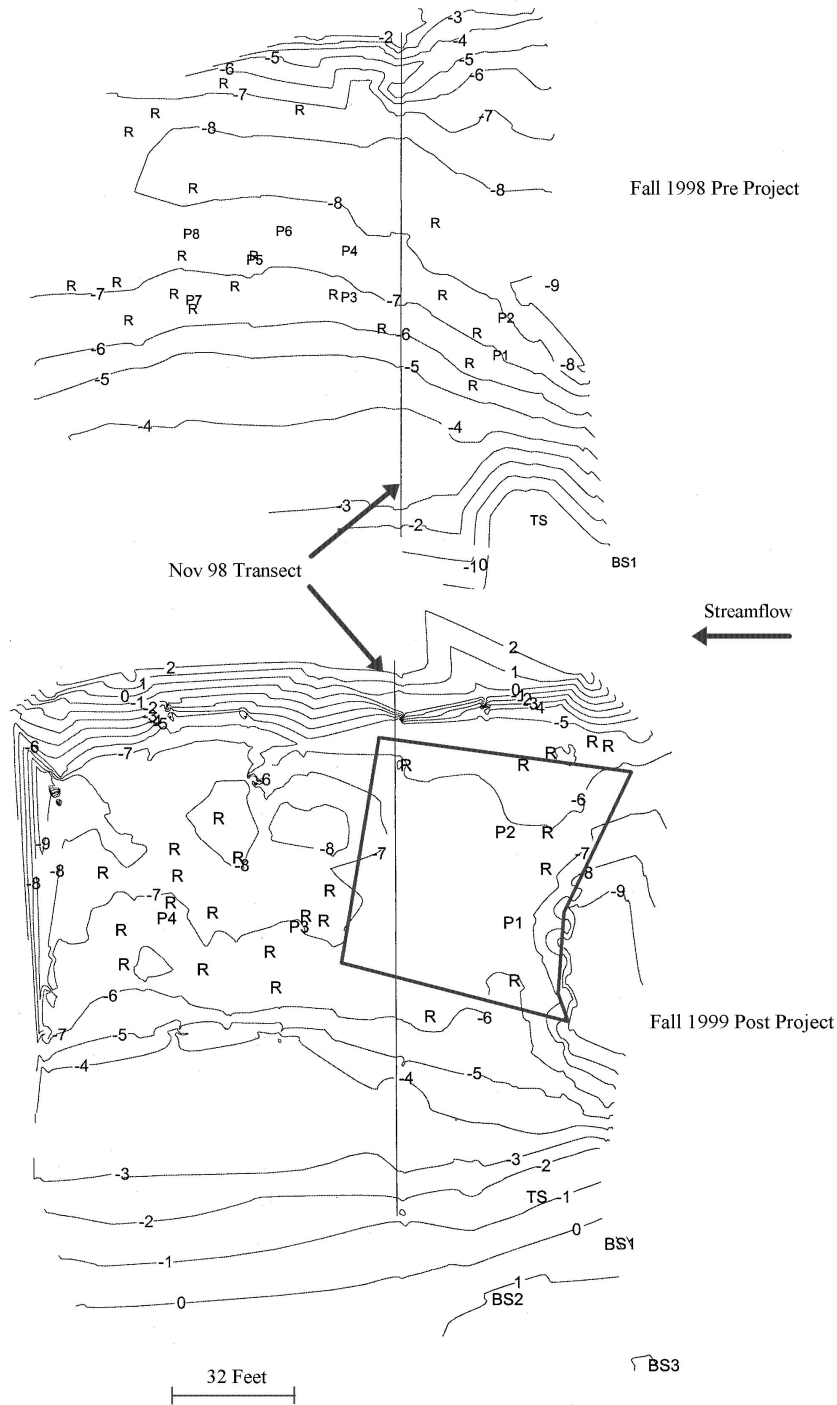


Figure 20. Contour maps of Riffle R43 at rivermile 46.9 on the Stanislaus River showing pre-project streambed elevations on 2 August 1999 (upper) and post-project elevations on 6 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -4.74 feet in August and -5.04 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 0.70 feet, BS2 is 1.245 feet, and BS3 is 2.110 feet.

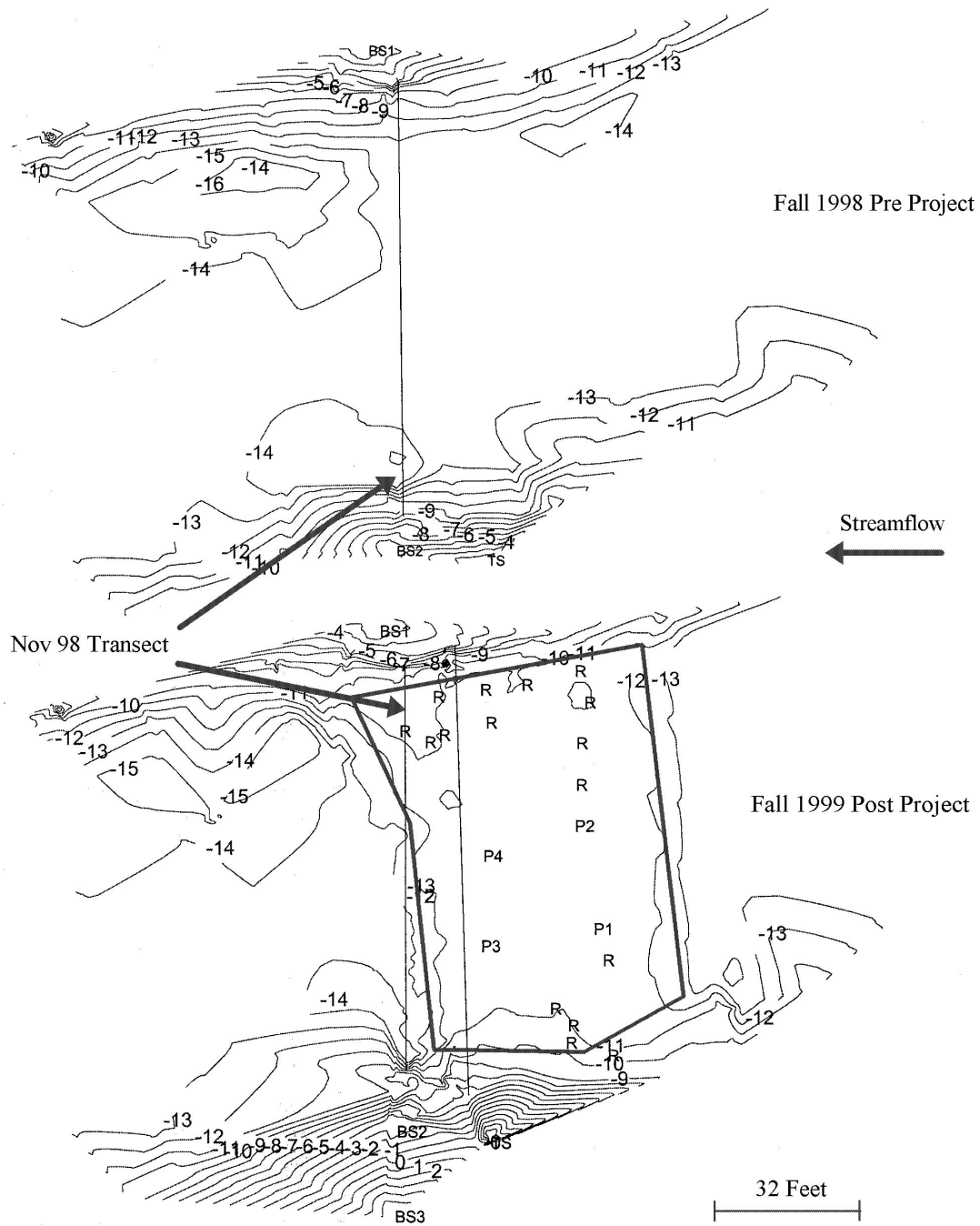


Figure 21. Contour maps of Riffle R57 at river mile 44.6 on the Stanislaus River showing pre-project streambed elevations on 17 August 1999 (upper) and post-project elevations on 5 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999, transects (vertical lines), total stations (TS), and 1999 piezometers (P). The water surface elevation at the transect was -9.78 feet in August and -9.84 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is -2.20 feet, BS2 is -3.325 feet, and BS3 is 5.270 feet.

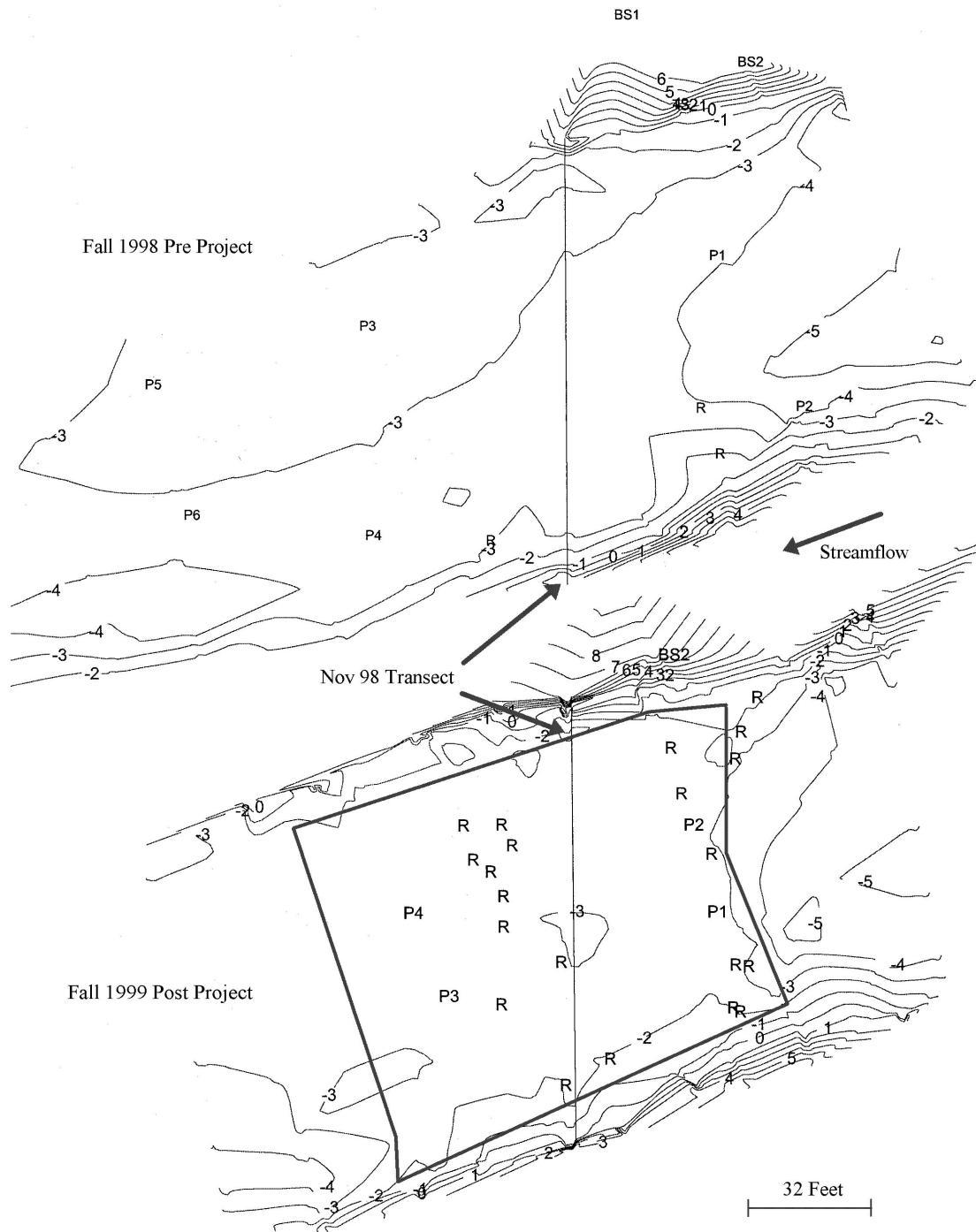


Figure 22. Contour maps of Riffle R58 at rivermile 44.5 on the Stanislaus River showing pre-project streambed elevations on 2 August 1999 (upper) and post-project elevations on 4 December 1999. The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was -0.955 feet in August and -1.095 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 11.45 feet, BS2 is 7.00 feet, and BS3 is 8.785 feet.

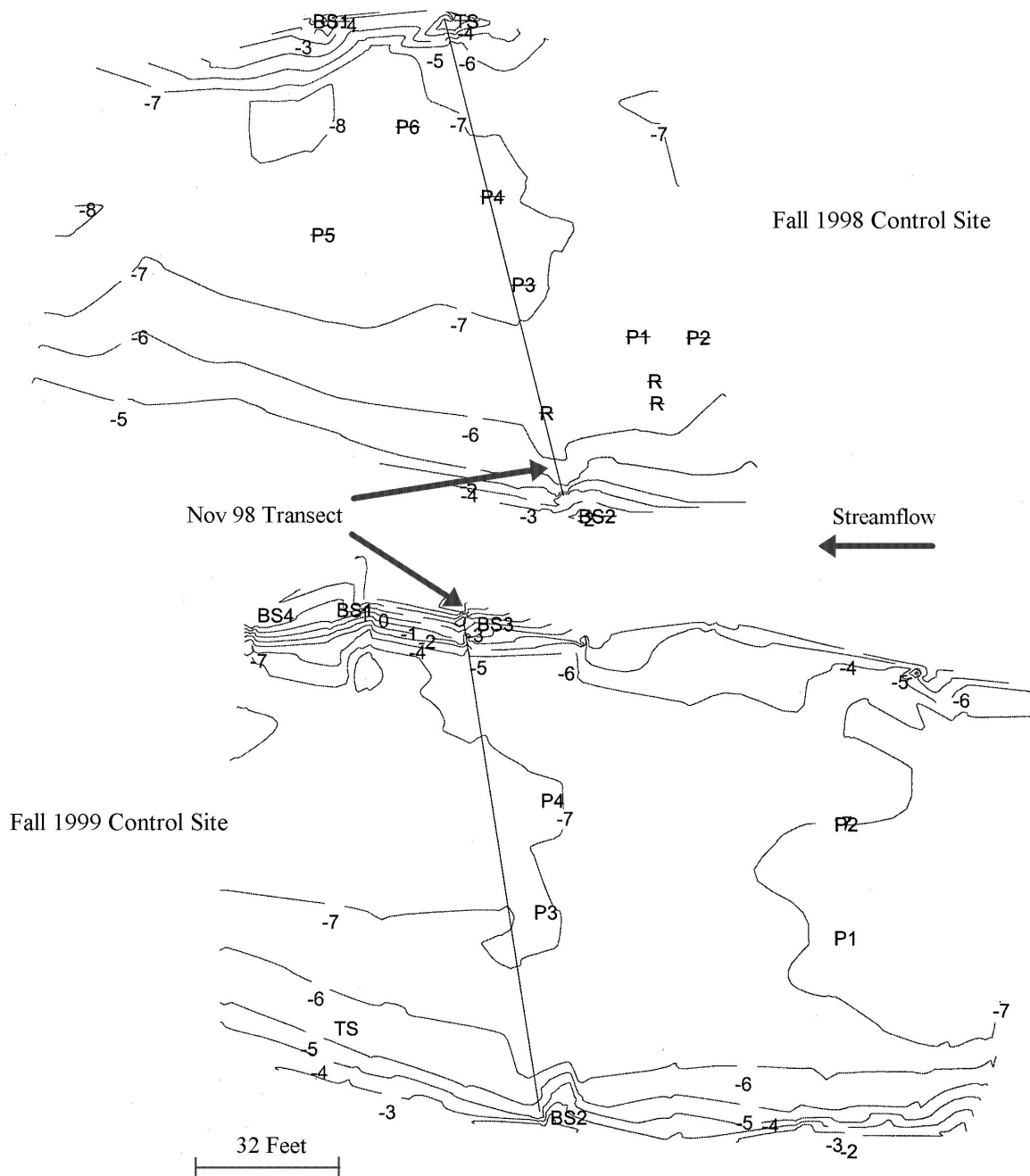


Figure 23. Contour maps of Riffle R59 at river mile 44.4 on the Stanislaus River showing streambed elevations measured on 20 August 1999 (upper) and 4 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1998 (upper) and 1999 (lower), transects (vertical lines), total stations (TS), 1998 standpipes (P) and 1999 piezometers (P). The water surface elevation at the transect was -4.435 feet in August and -5.01 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is -1.635 feet, BS3 is -2.300 feet, and BS4 is -0.130 feet.

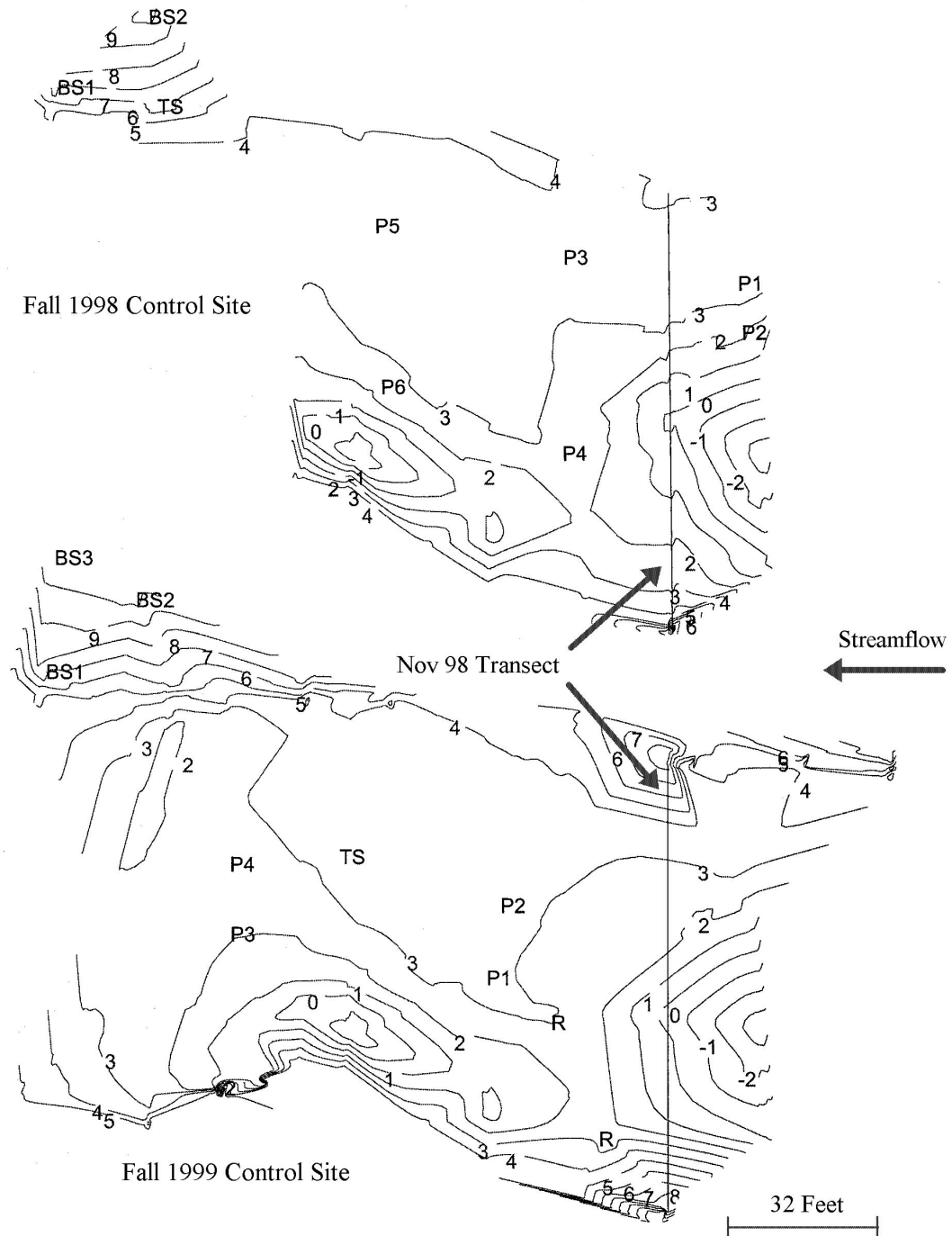


Figure 24. Contour maps of Riffle R76 at river mile 40.35 on the Stanislaus River showing streambed elevations measured on 19 August 1999 (upper) and 5 December 1999 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999, transects (vertical lines), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was 5.475 feet in August and 4.62 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 8.065 feet, BS2 is 10.295 feet, and BS3 is 10.760 feet.

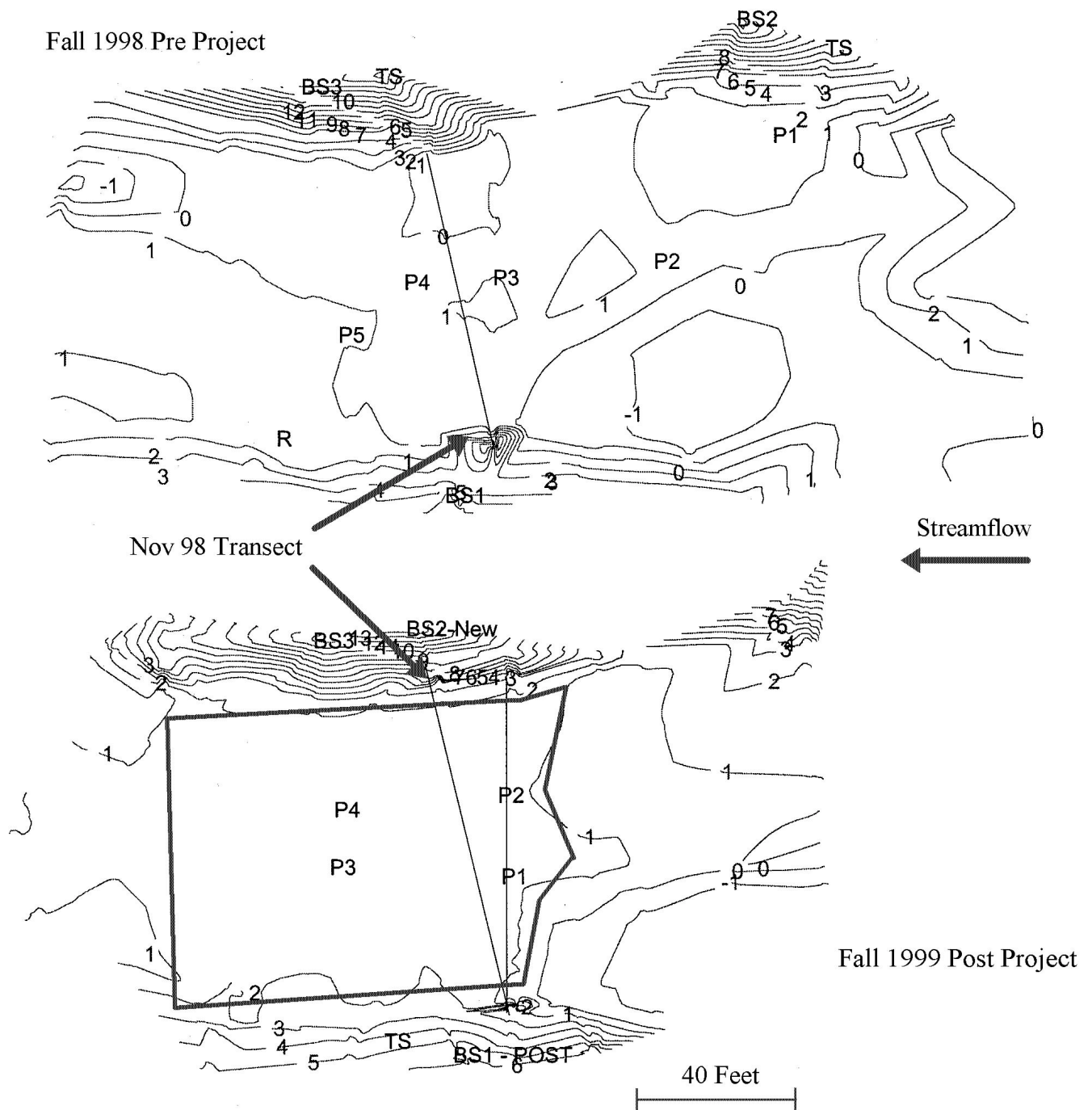


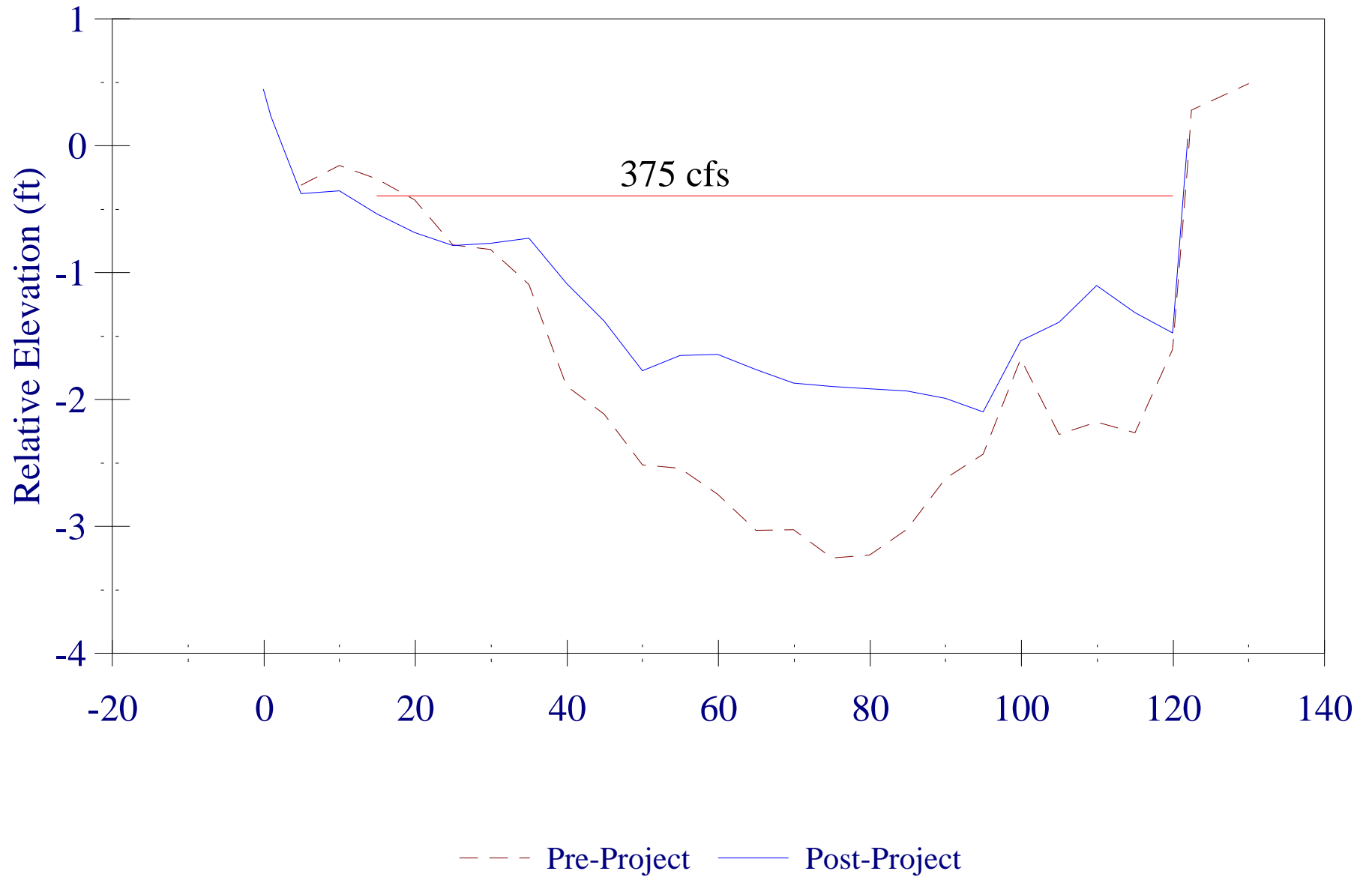
Figure 25. Contour maps of Riffle R78 at river mile 40.2 on the Stanislaus River showing pre-project streambed elevations on 16 August 1999 (upper) and post-project elevations on 5 December 1999 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1998 (upper), transects (vertical line), total stations (TS), 1998 standpipes (P), and 1999 piezometers (P). The water surface elevation at the transect was 3.22 feet in August and 3.325 feet in December. The elevation of the top of the metal pins at backsight 1 (BS1) is 6.00 feet, a new BS2 is 15.995 feet, and BS3 is 13.07 feet.

APPENDIX 4

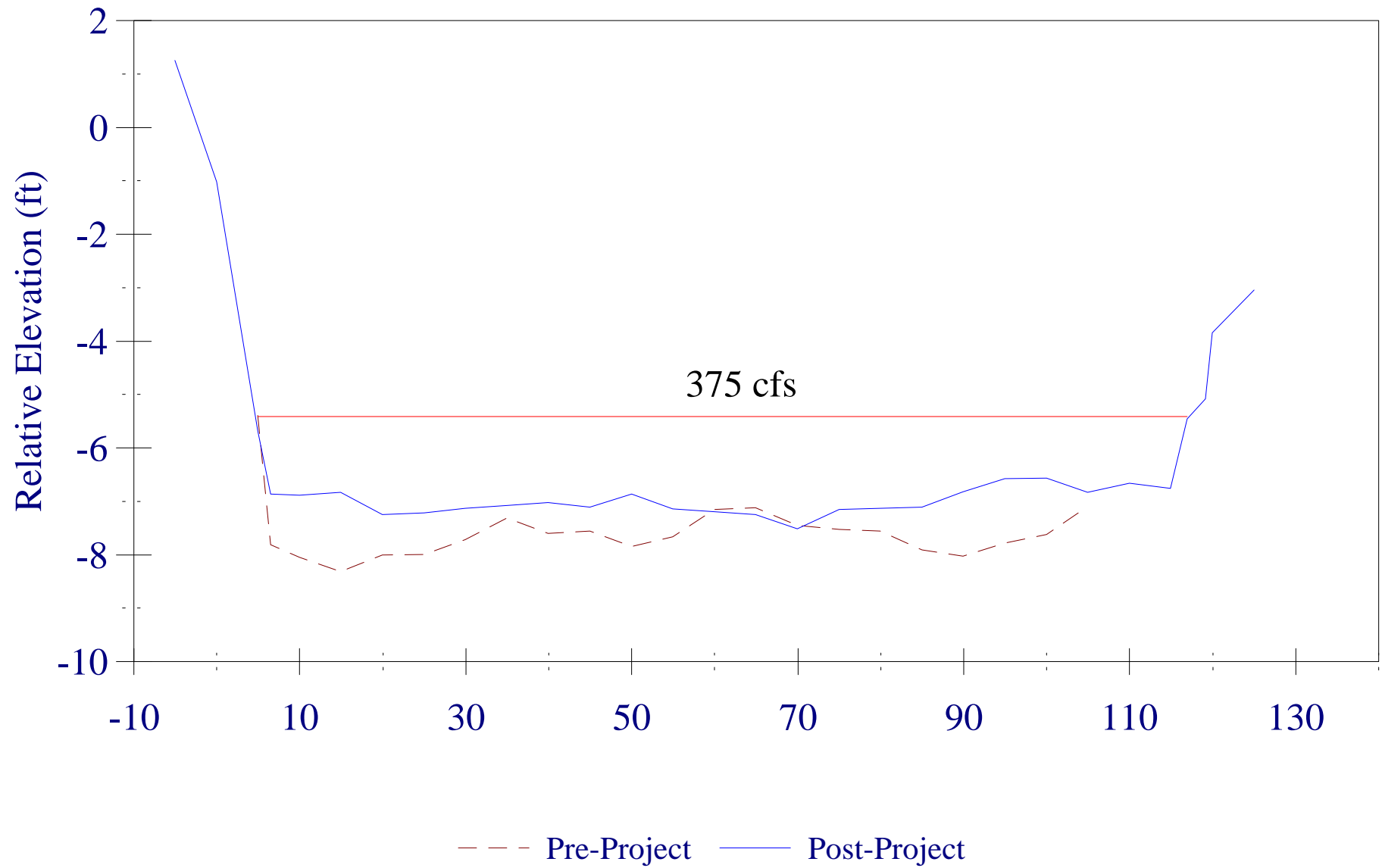
Figures of Pre- and Post-Project Streambed Elevations

The relative streambed and water surface elevations were measured at transects for pre-project conditions in August 1999 and post-project conditions in September 1999 for 18 project riffles. The elevations for pre-project conditions for riffles R5, R12A, R13, R14A, R15, R16, R19, R19A, and R57 were estimated by superimposing the locations of new transects established between 24 August and 29 September 1999 onto the pre-project contour maps in Appendix 3 and then by interpolating between the contour lines and using nearby measured values. The elevations shown in these graphs are comparable to those in the contour maps in Appendix 3.

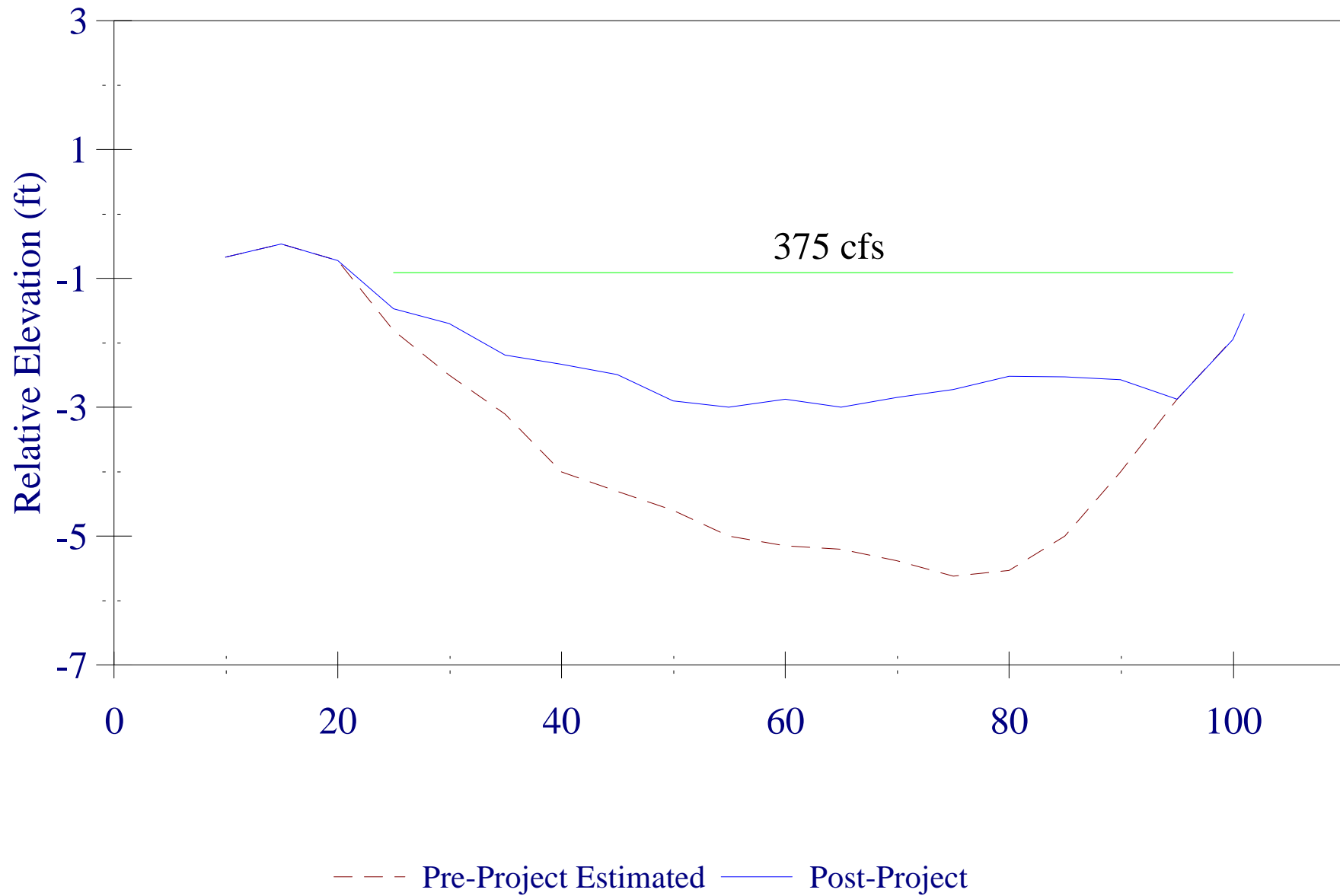
TMA



R1



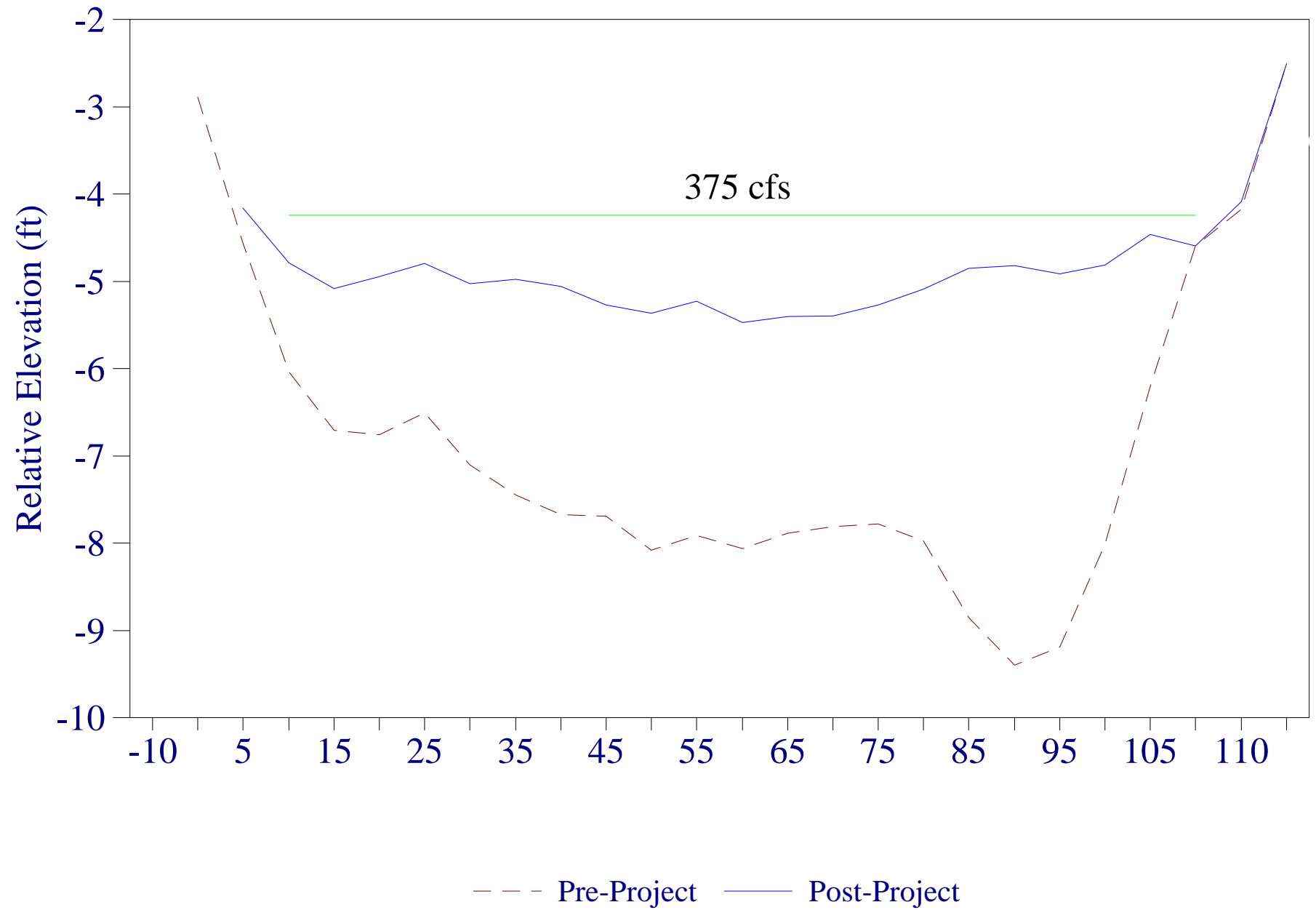
R5



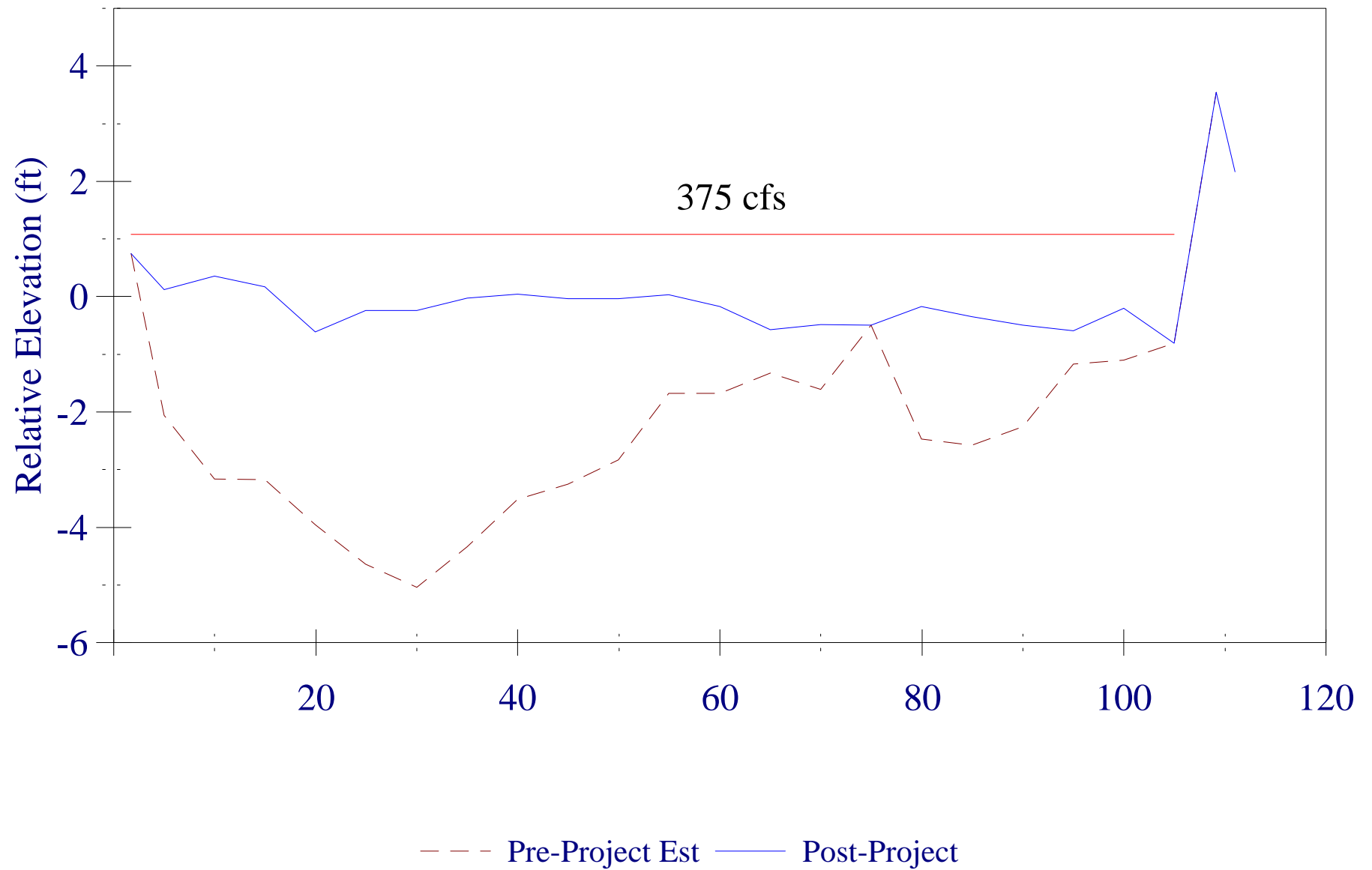
R12A



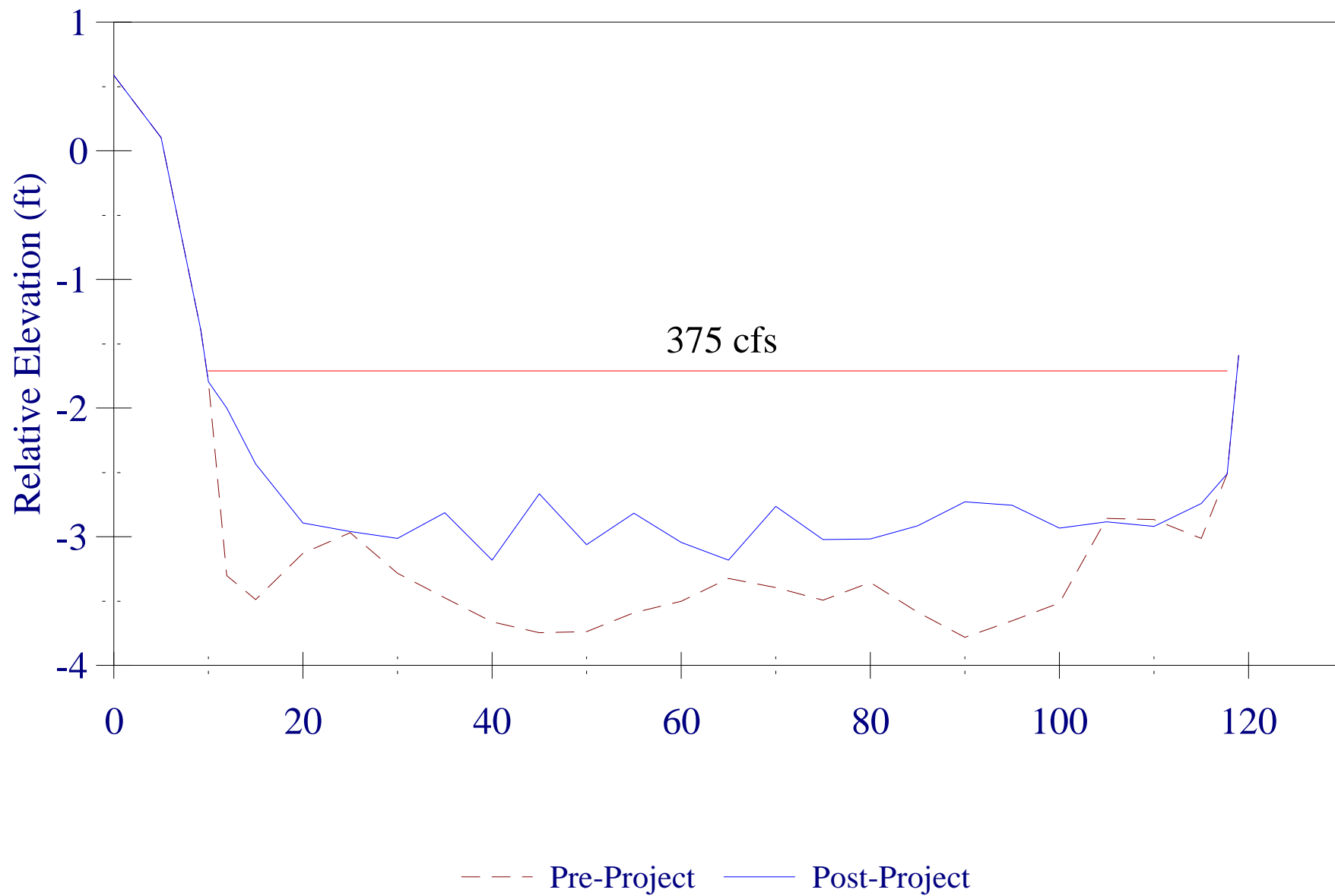
R12B



R13



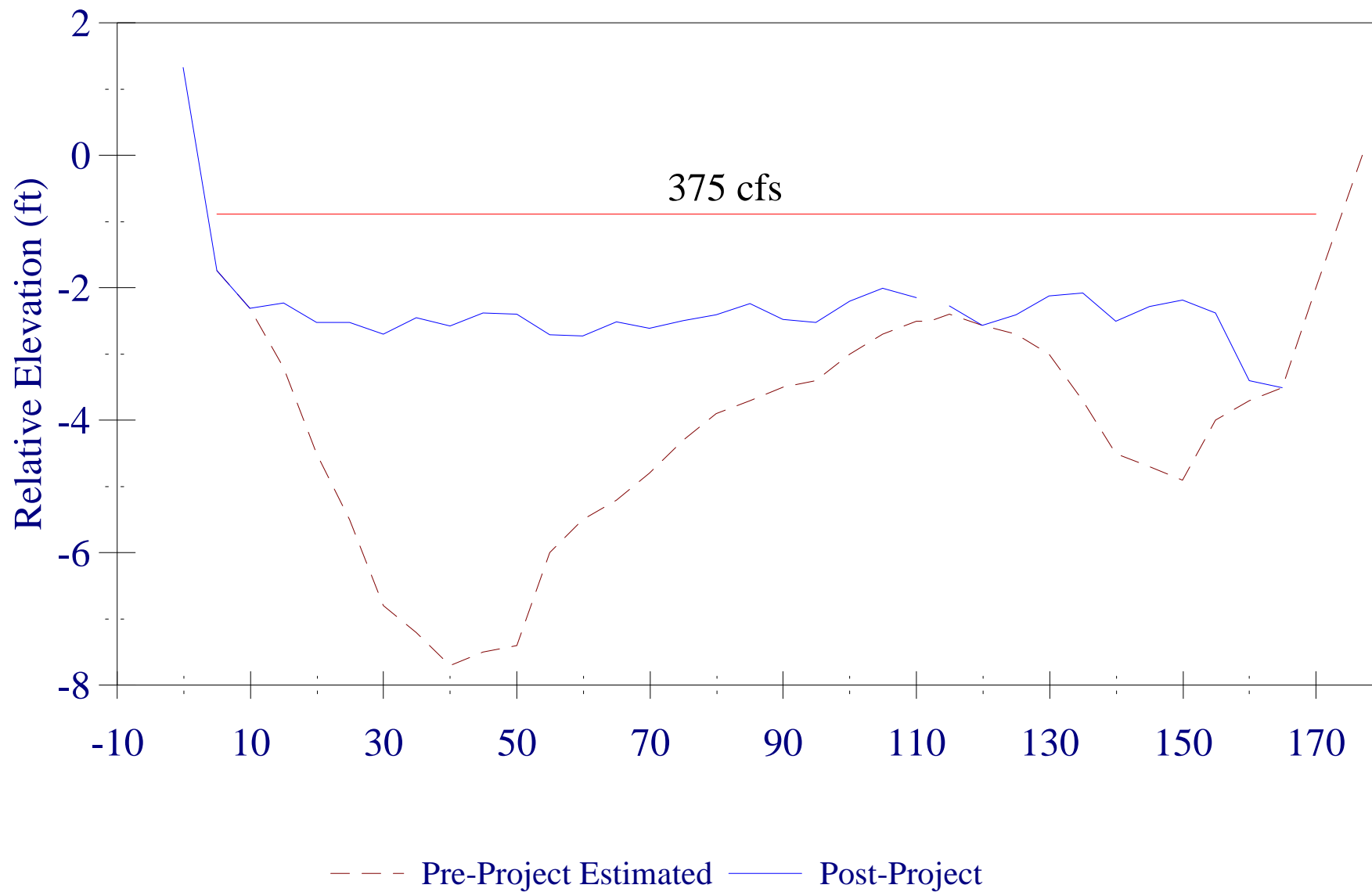
R14



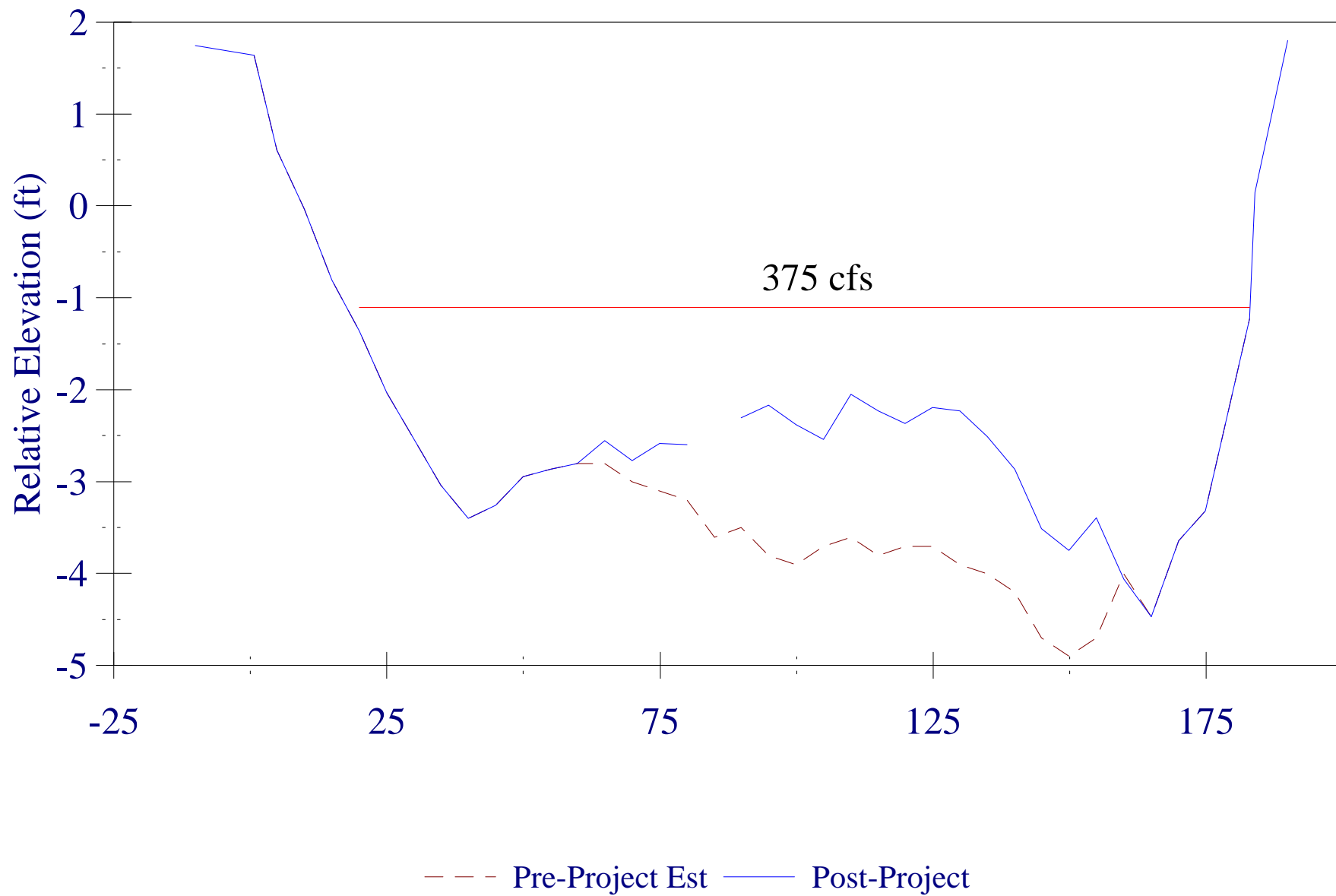
R14A



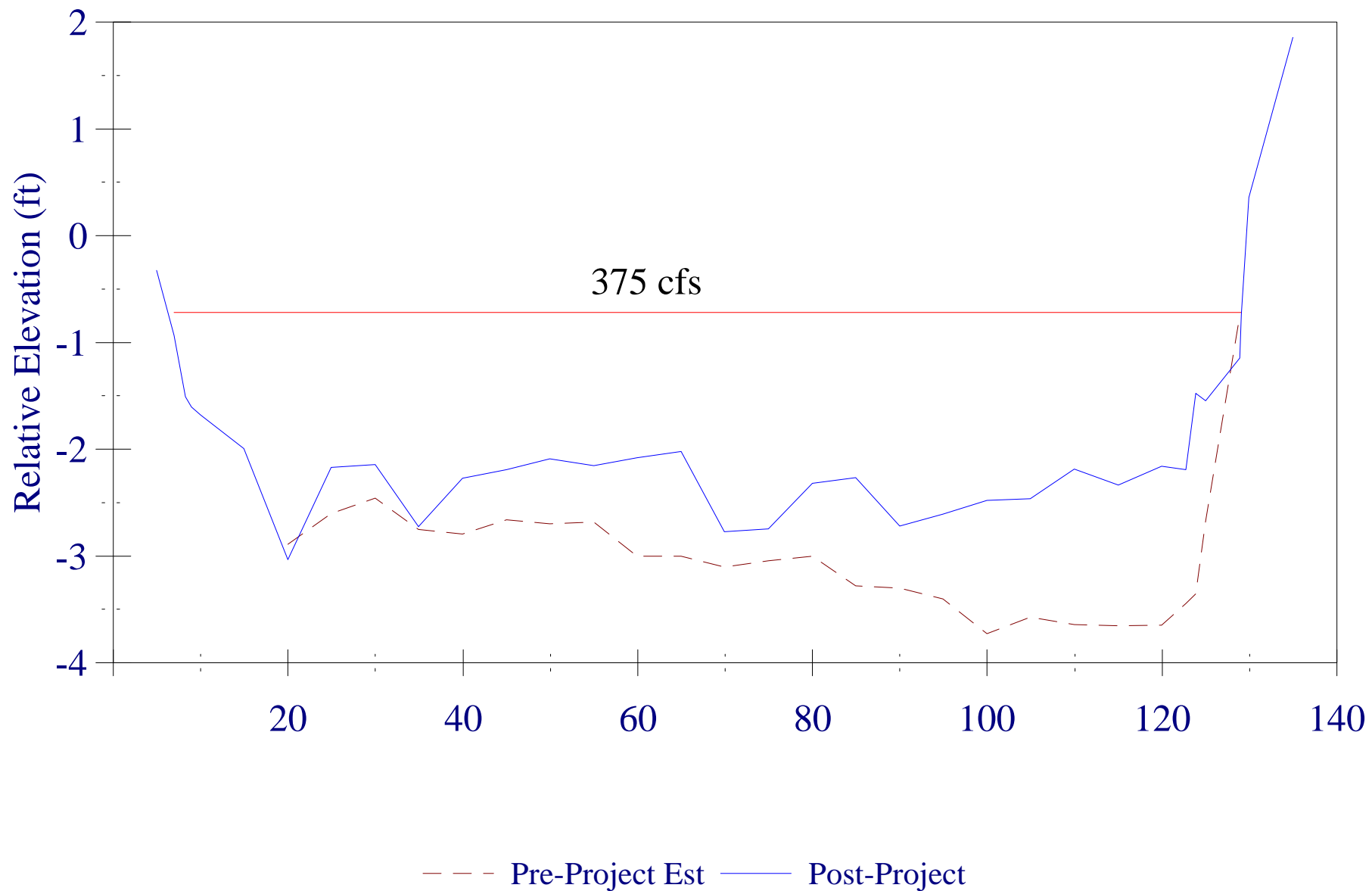
R15



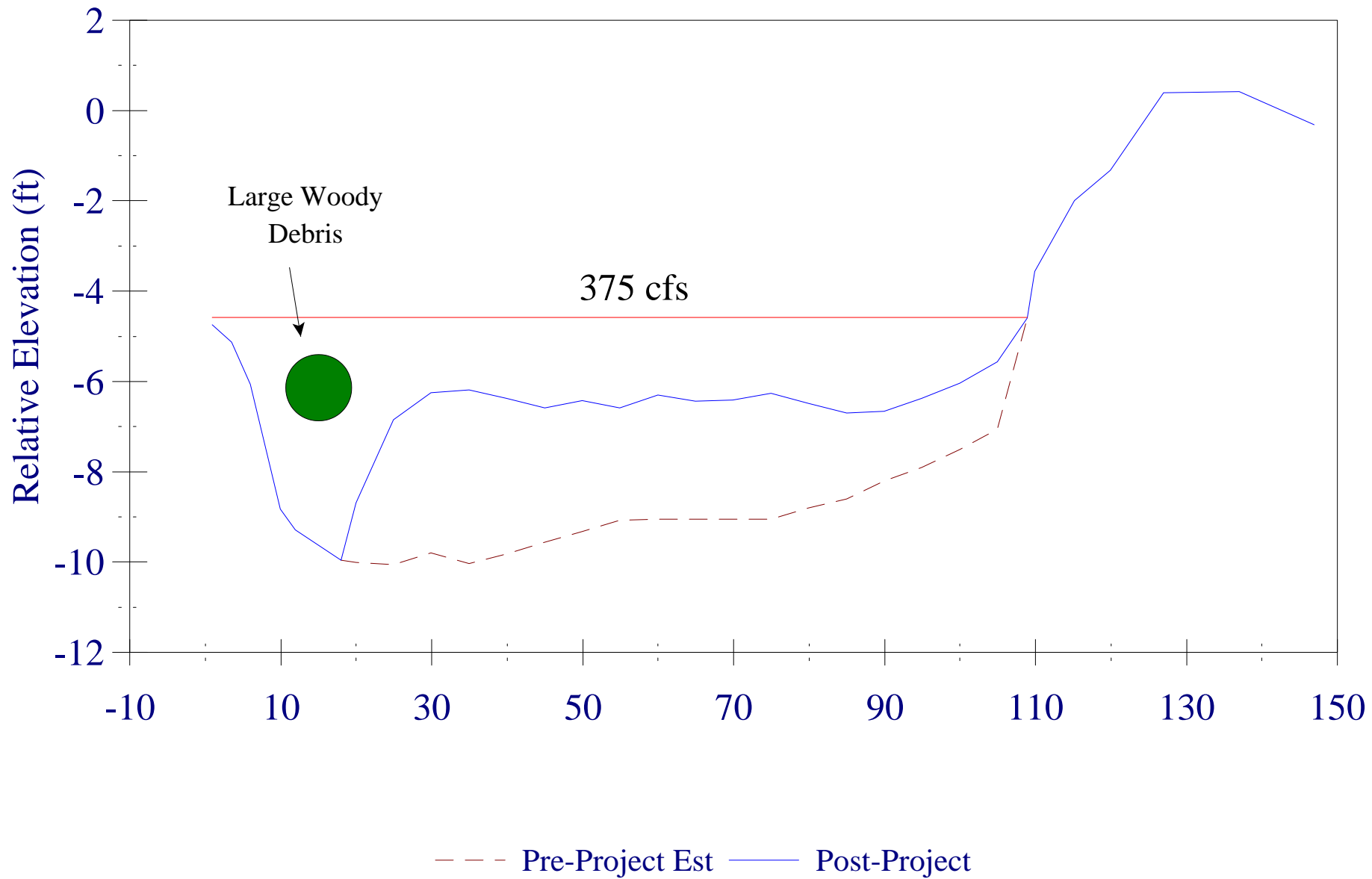
R16



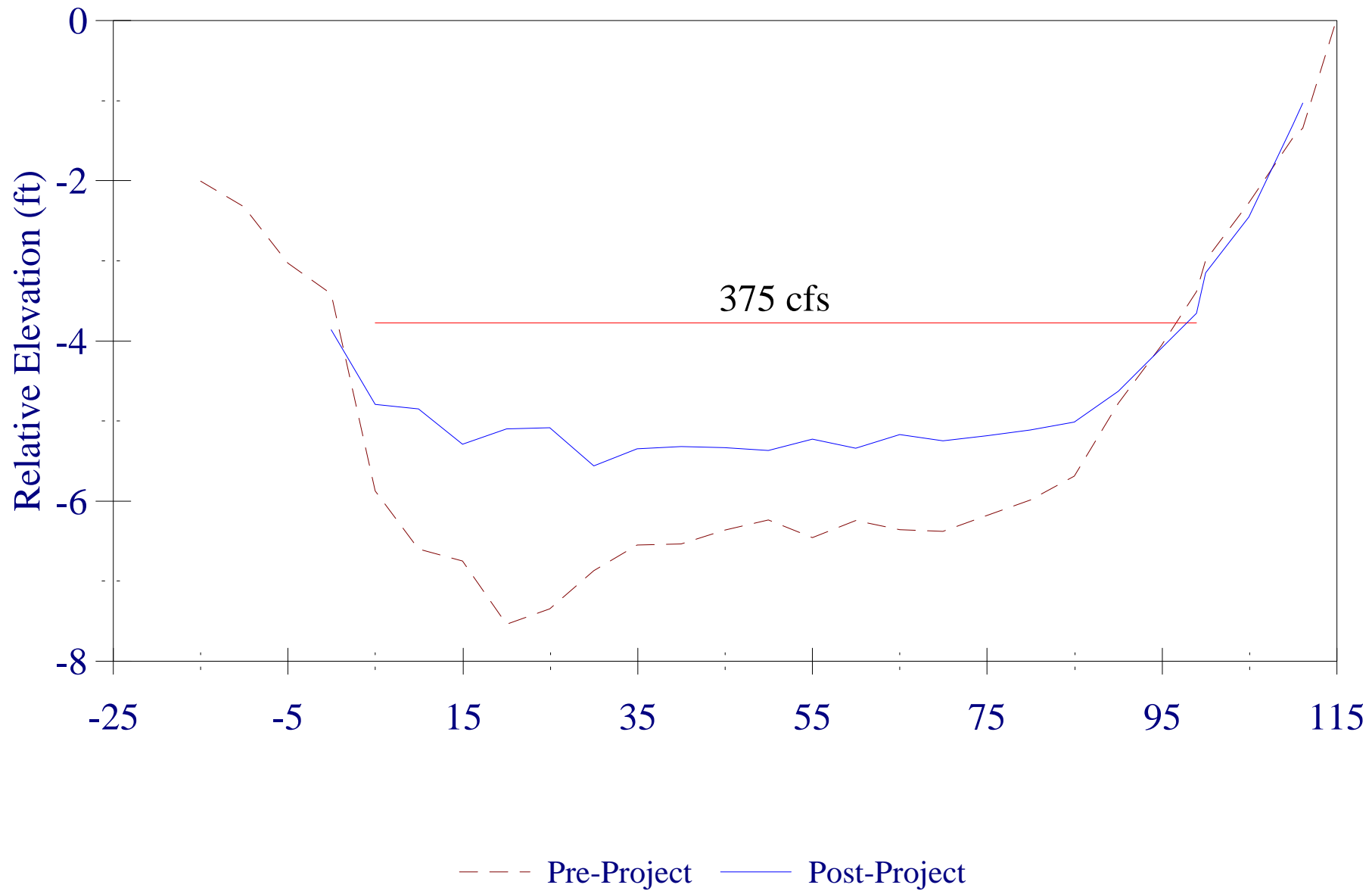
R19



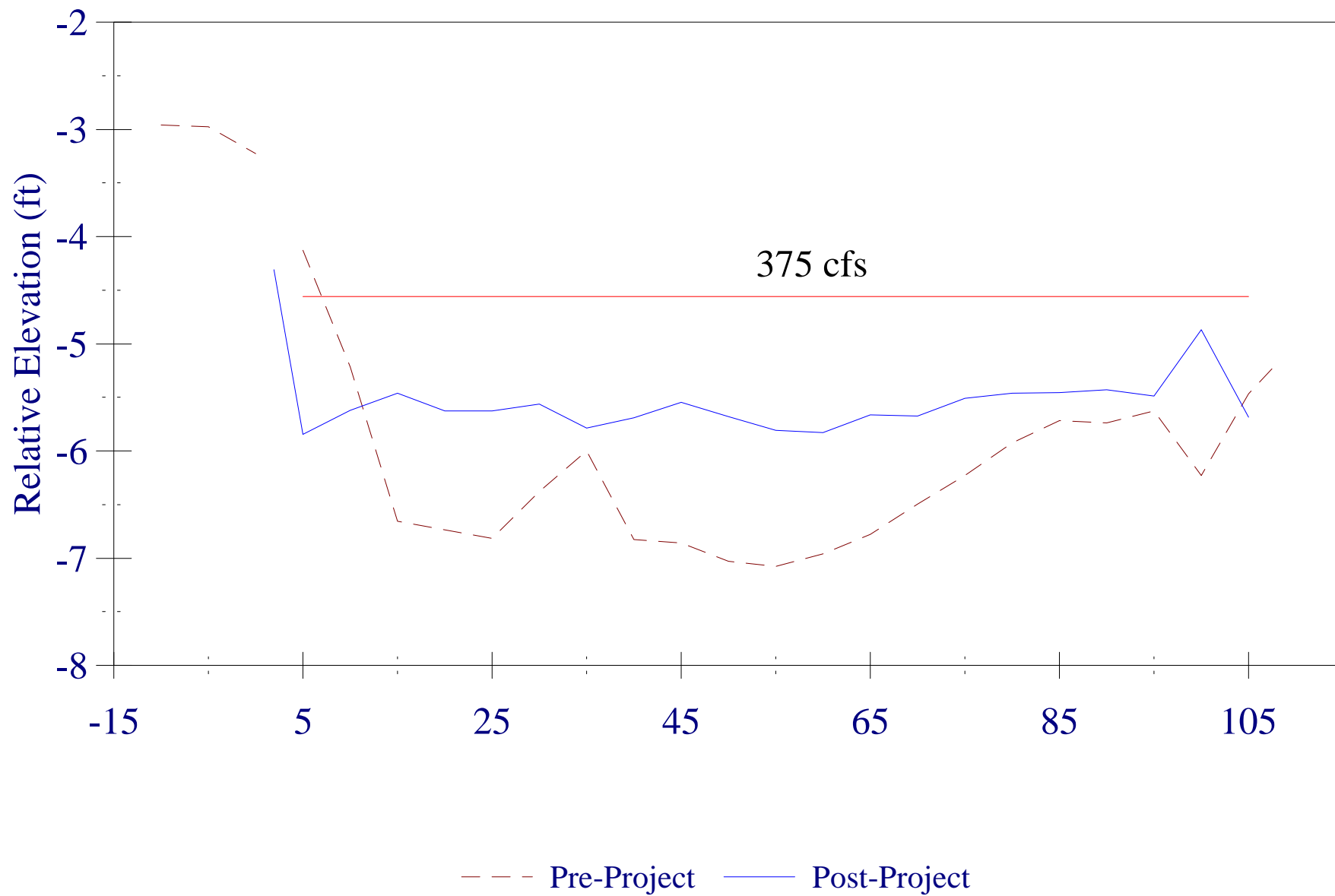
R19A



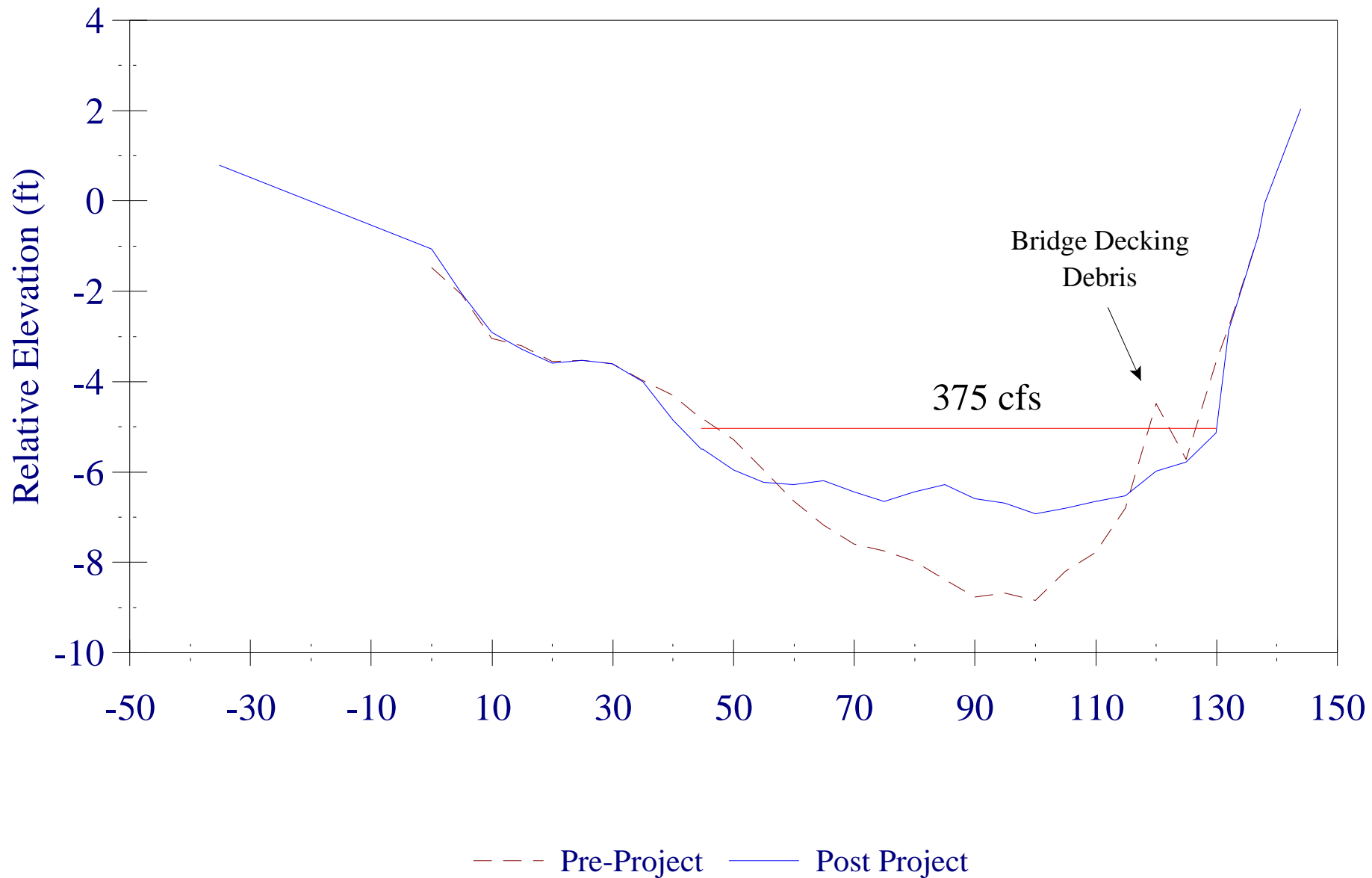
R28A



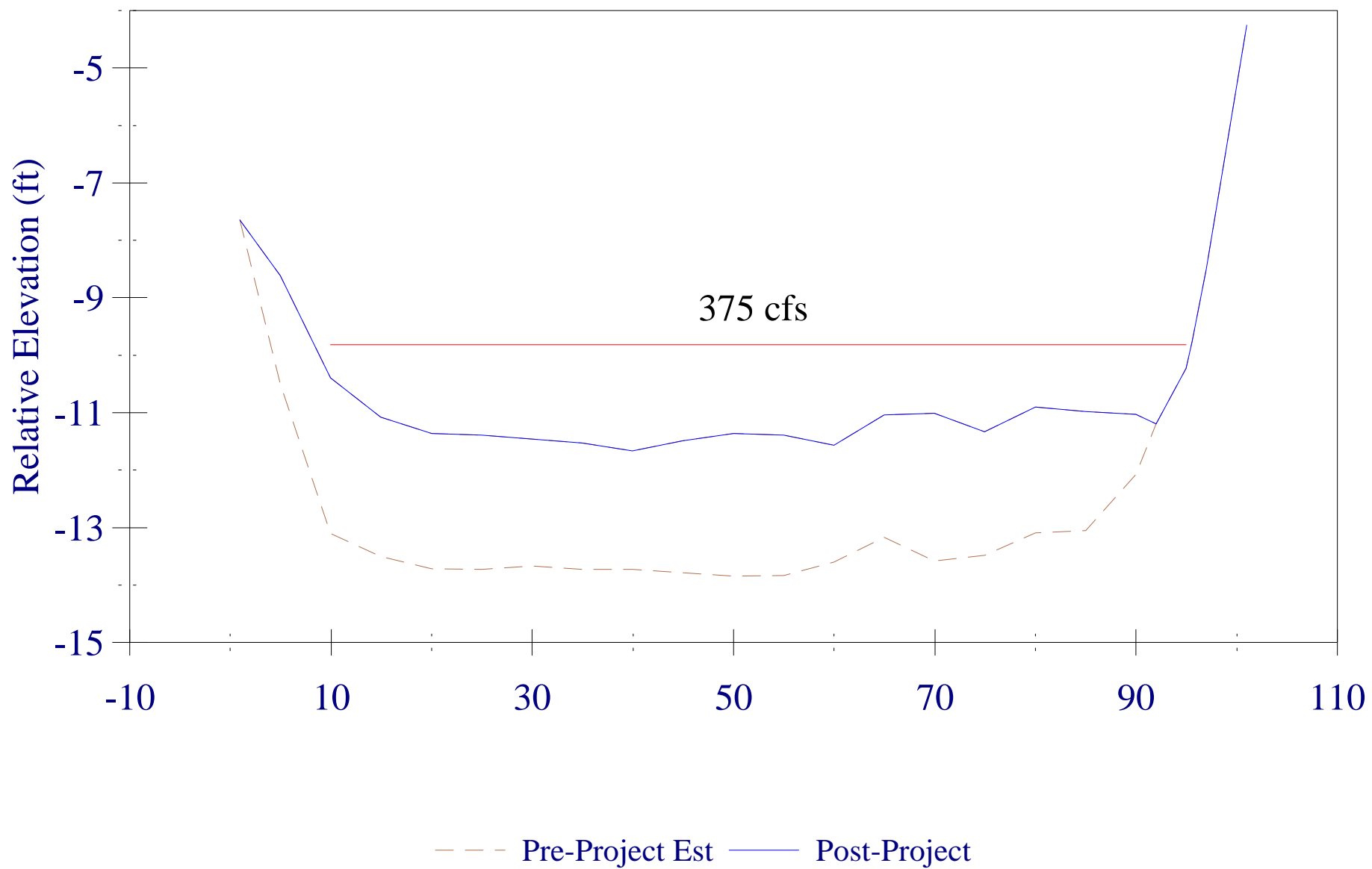
R29



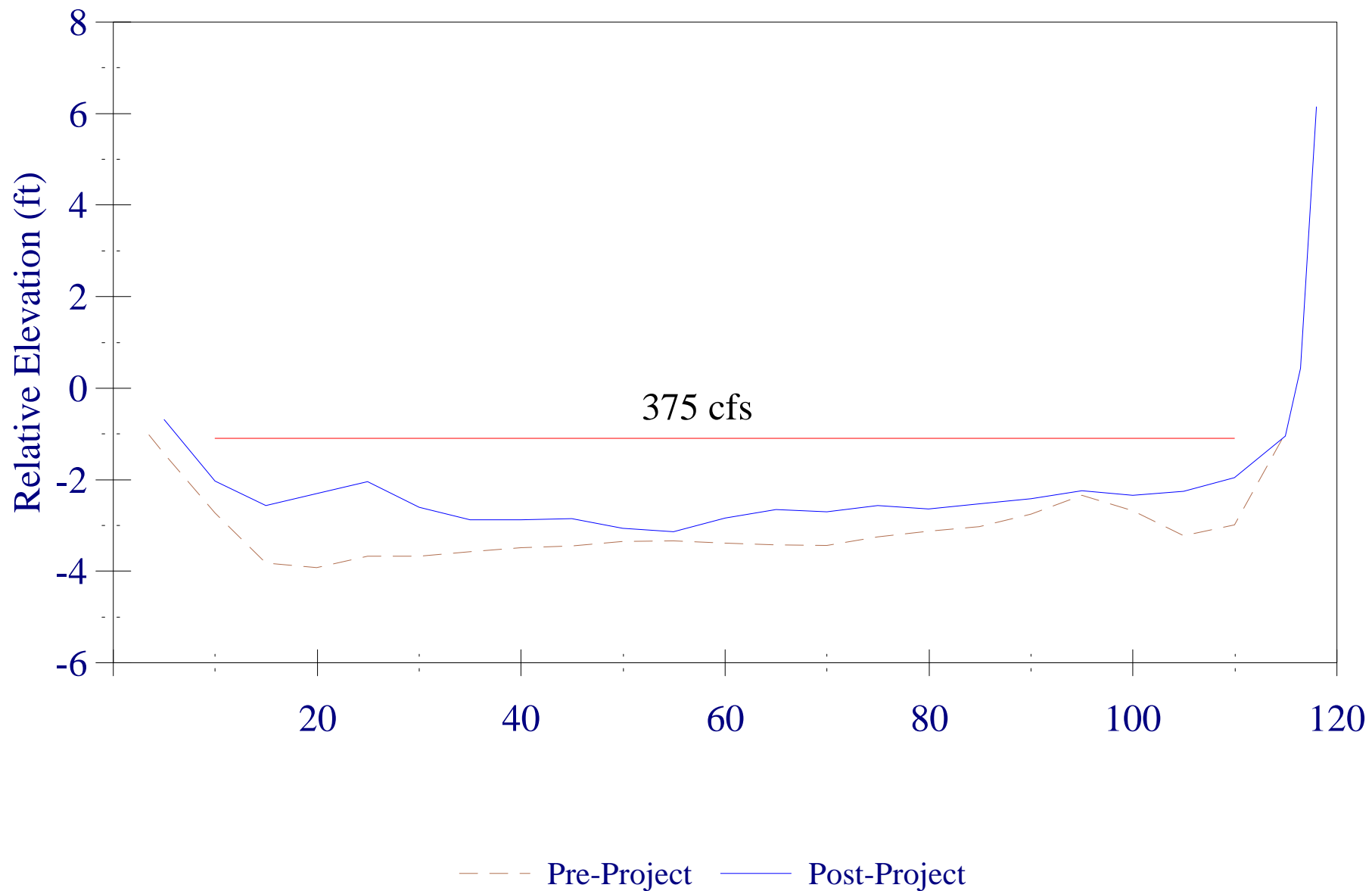
R43



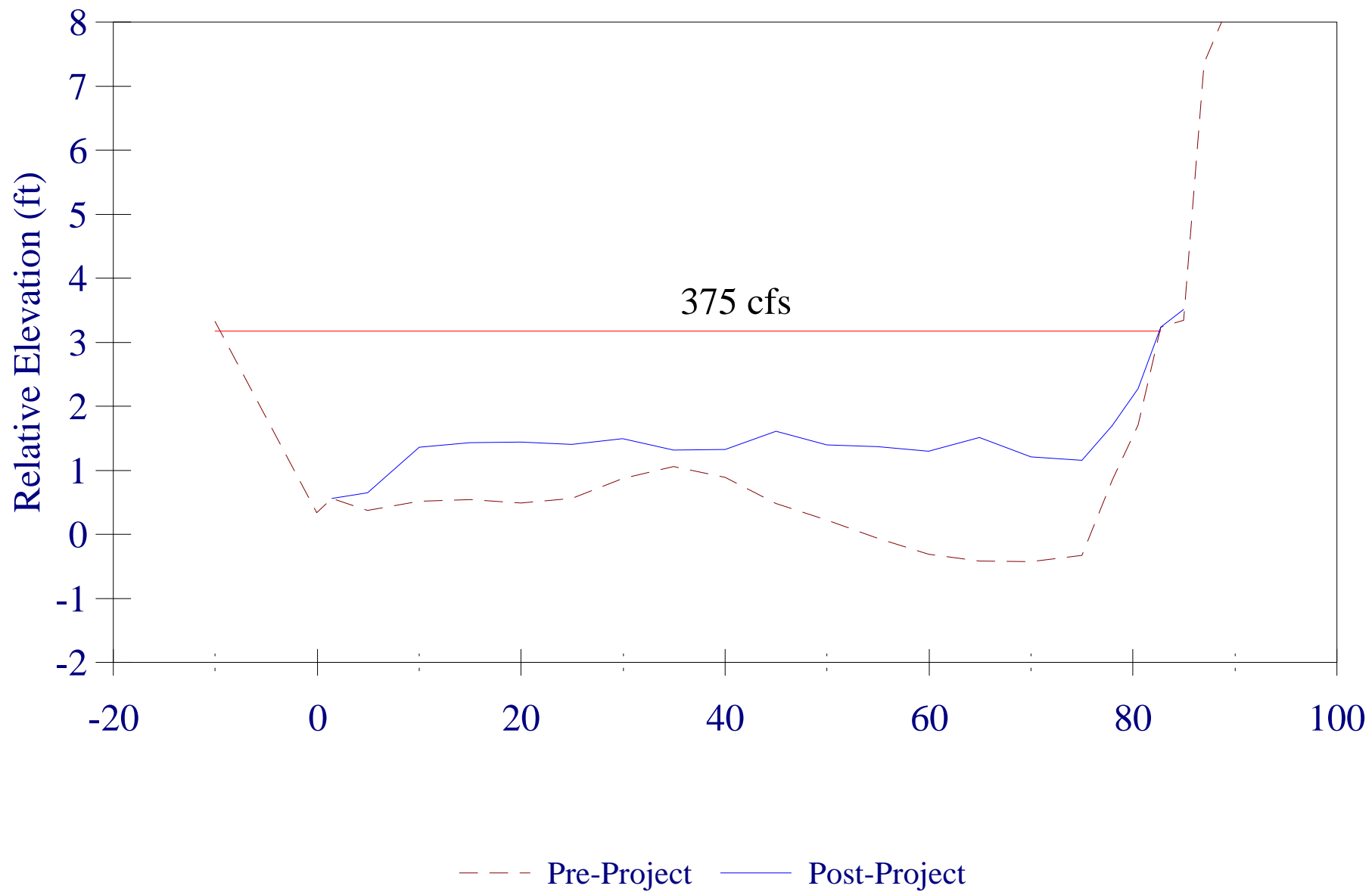
R57



R58



R78



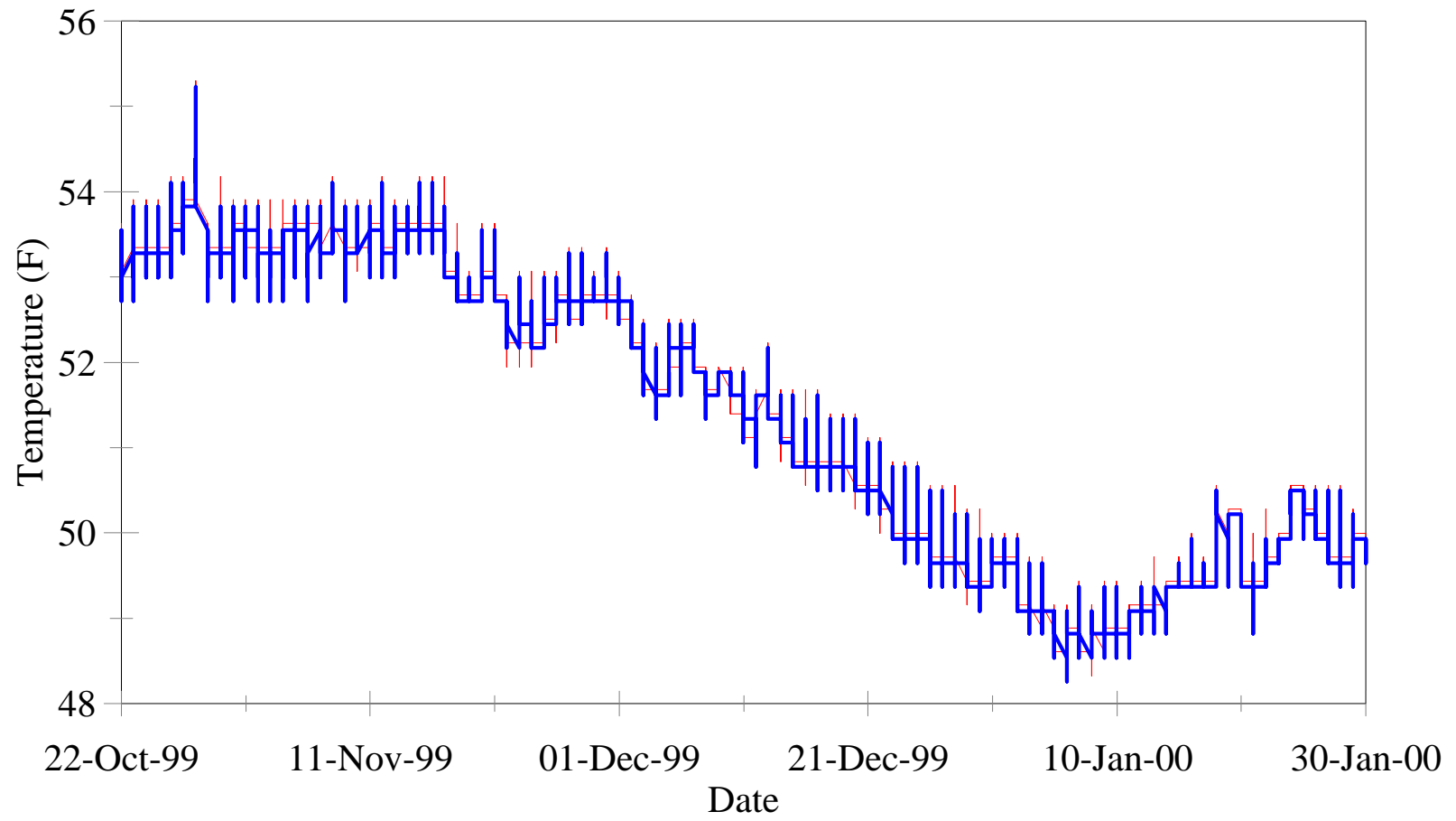
APPENDIX 5

Intragravel and Surface Water Temperatures from October 1999 to March 2000.

Intragravel water temperatures were measured at 30-minute intervals with *Onset Tidbit* thermographs buried with piezometers in artificial redds at 25 study riffles in the Stanislaus river between Goodwin Dam and Oakdale. Thermographs also monitored surface flows near the river margin near riffles DFG2, TMA, R5, R10, R14, R19, R28A, R43, R59, and R76. Comparisons between surface and intragravel measurements at riffles where no surface thermograph was installed utilized the surface data collected at the closest riffle.

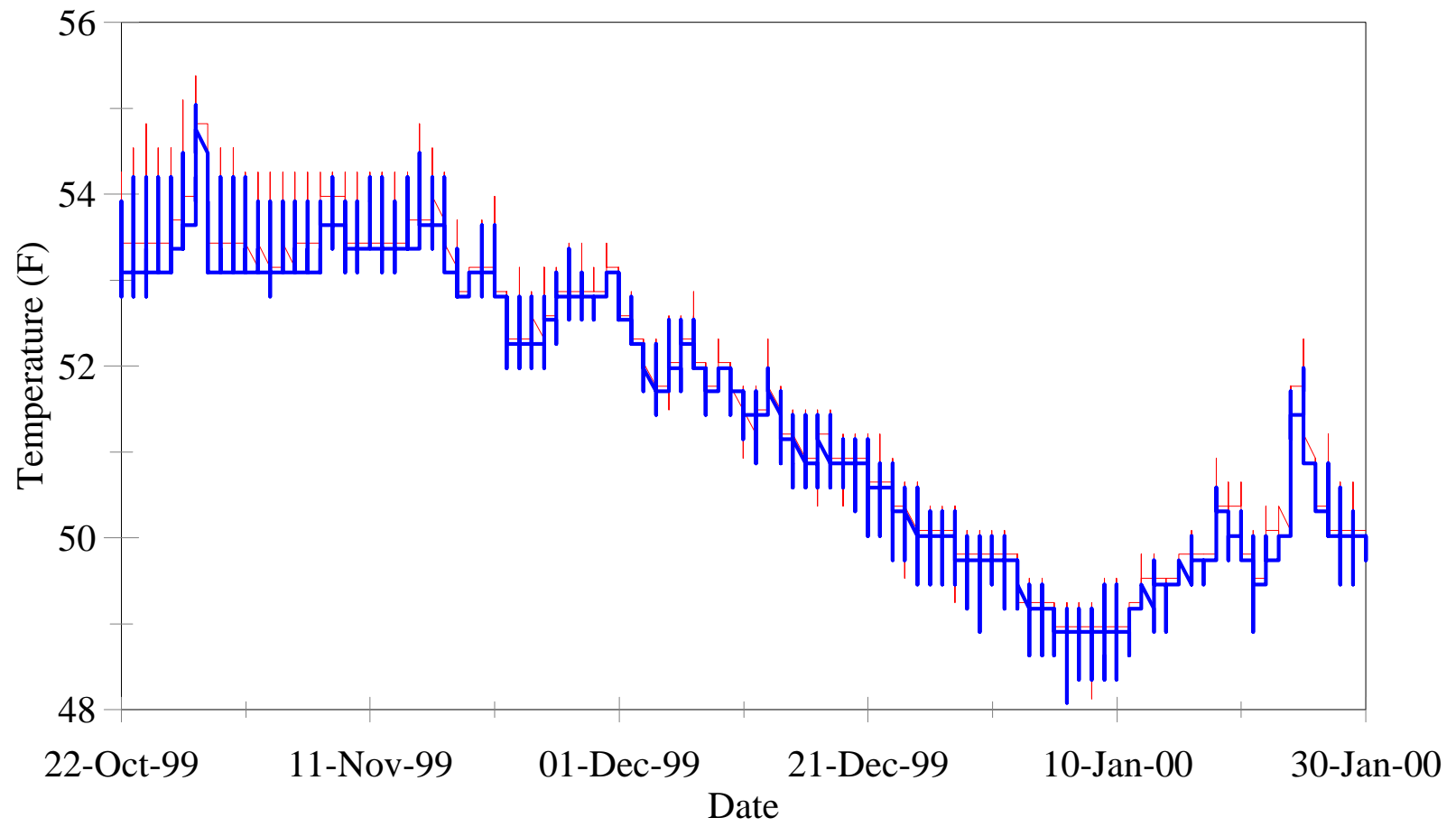
For 56 of the 92 buried thermographs that were recovered, the magnitude and fluctuation in intragravel water temperatures were nearly identical to those of the surface flow. As examples of these sites, thermograph data are presented in this appendix for the following piezometers: DFG2 P1, TMA P1, R12 P1, R15 P1, R28A P2, R43 P1, R57 P2, and R78 P2. The data from all the 36 buried thermographs that deviated in either magnitude or fluctuation from the surface temperatures are also presented in this appendix.

DFG2 P1



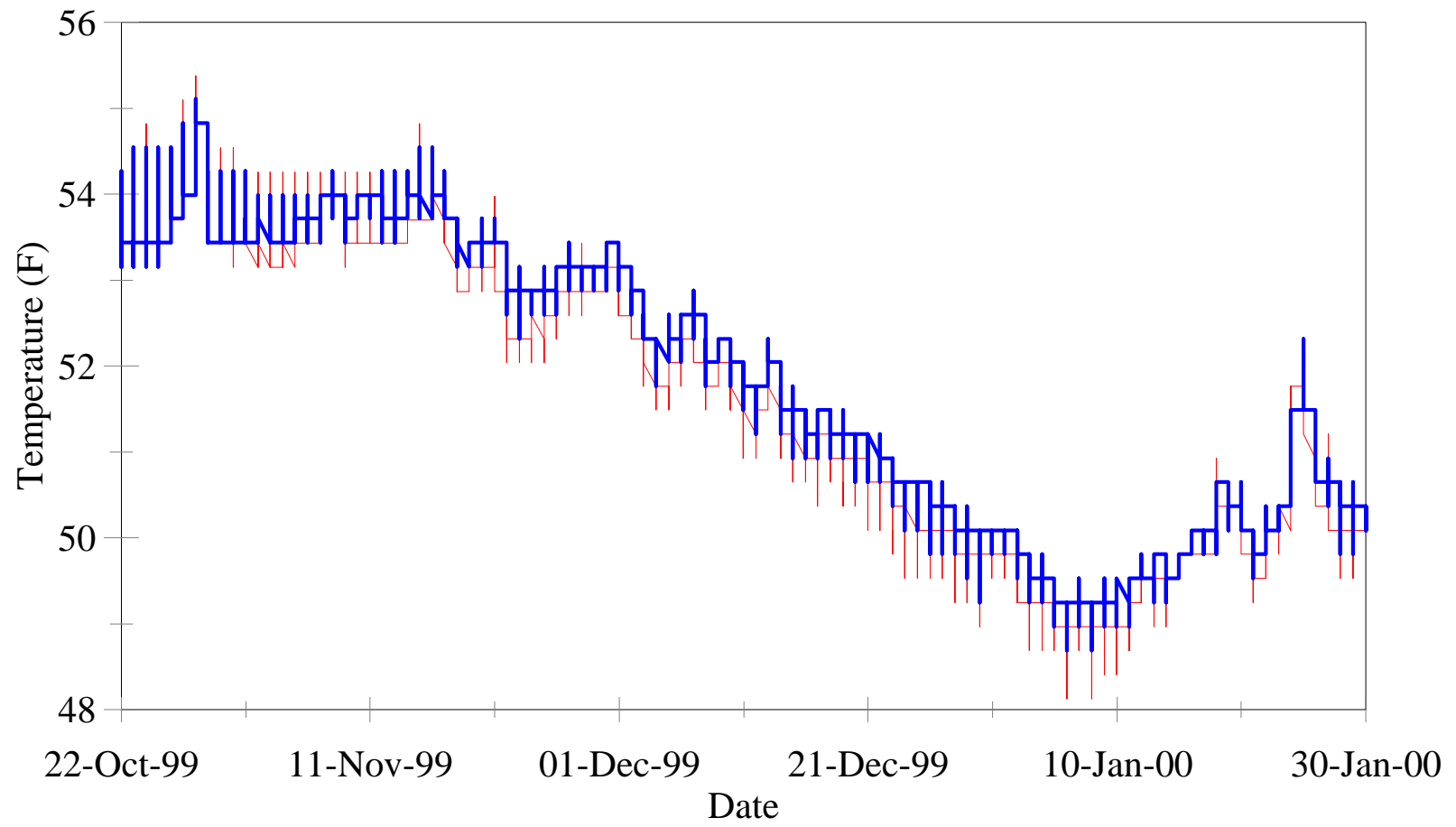
— Surface Temp — Intragravel Temp

TMA P1



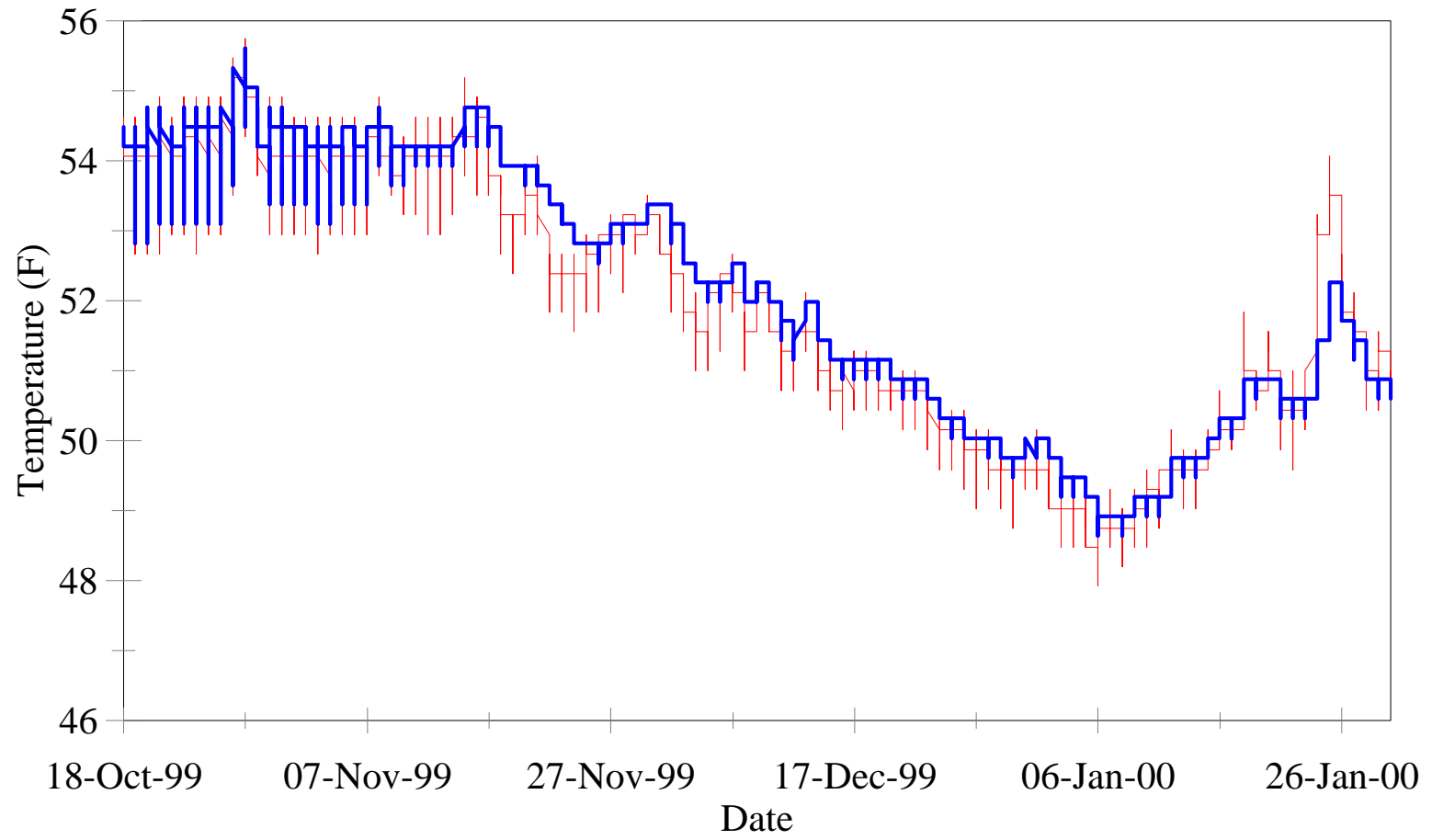
— Surface Temp — Intragravel Temp

TM1 P4



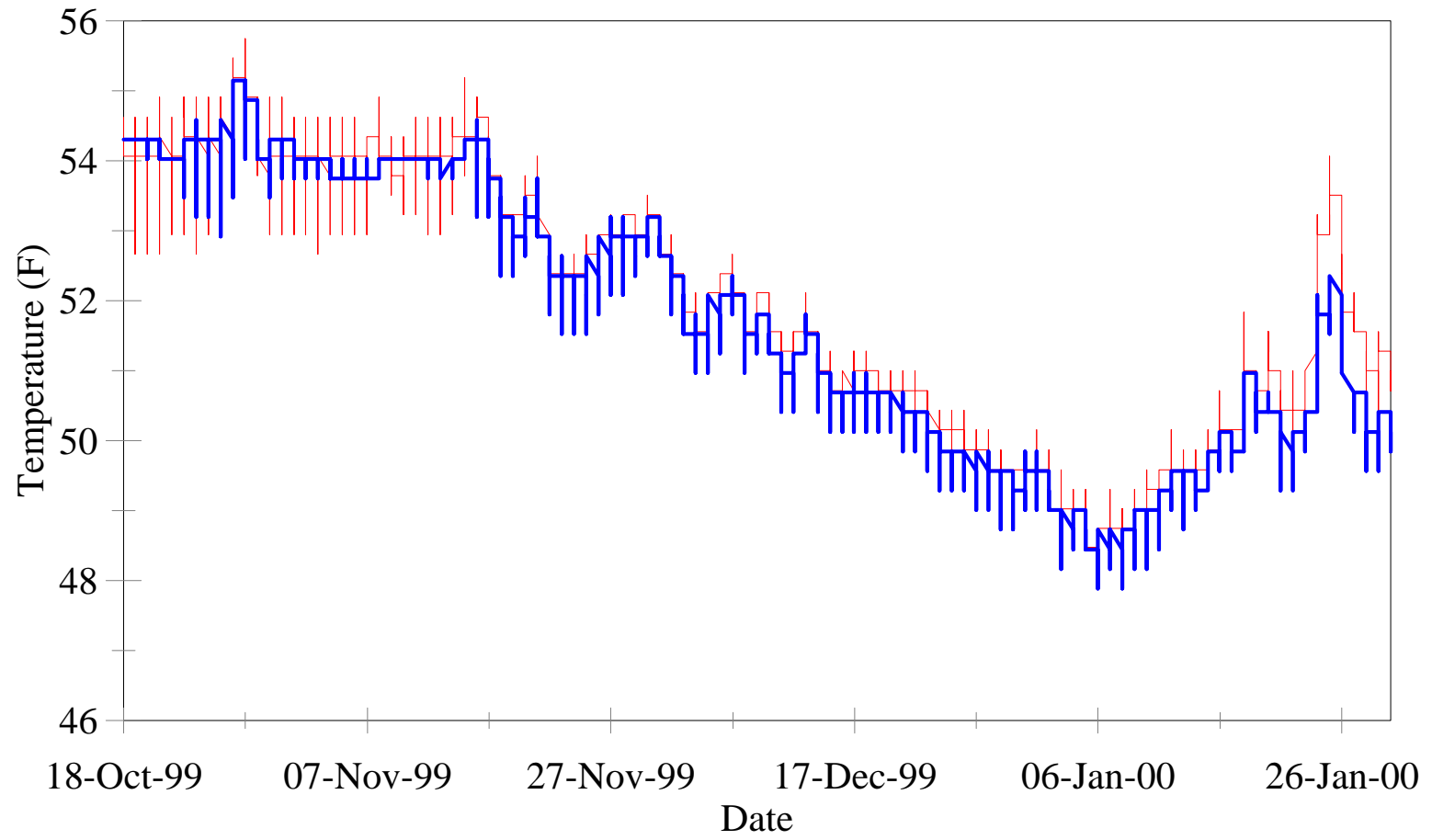
— Surface Temp — Intragravel Temp

R10 P1



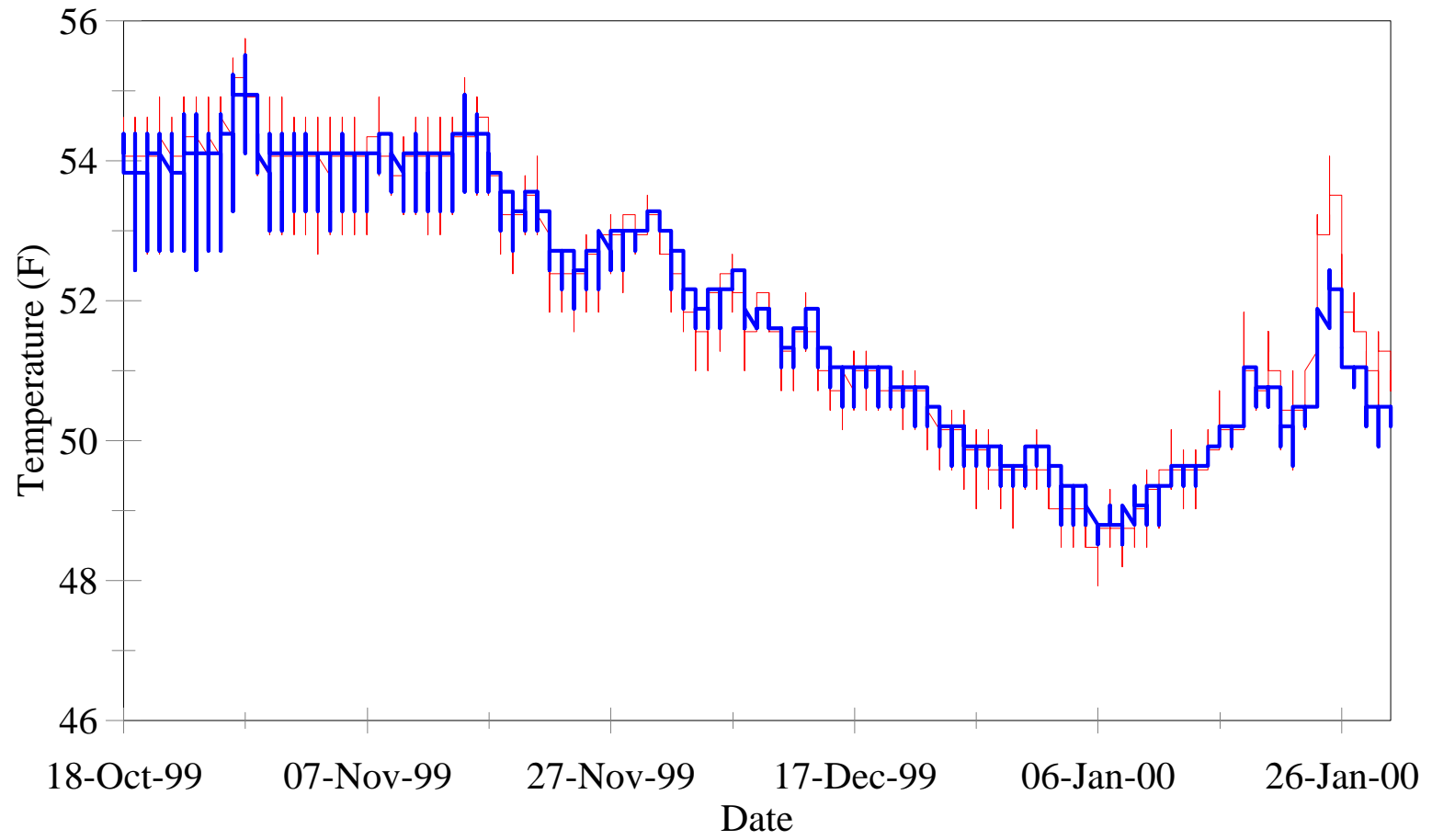
— Surface Temp — Intragravel Temp

R10 P2



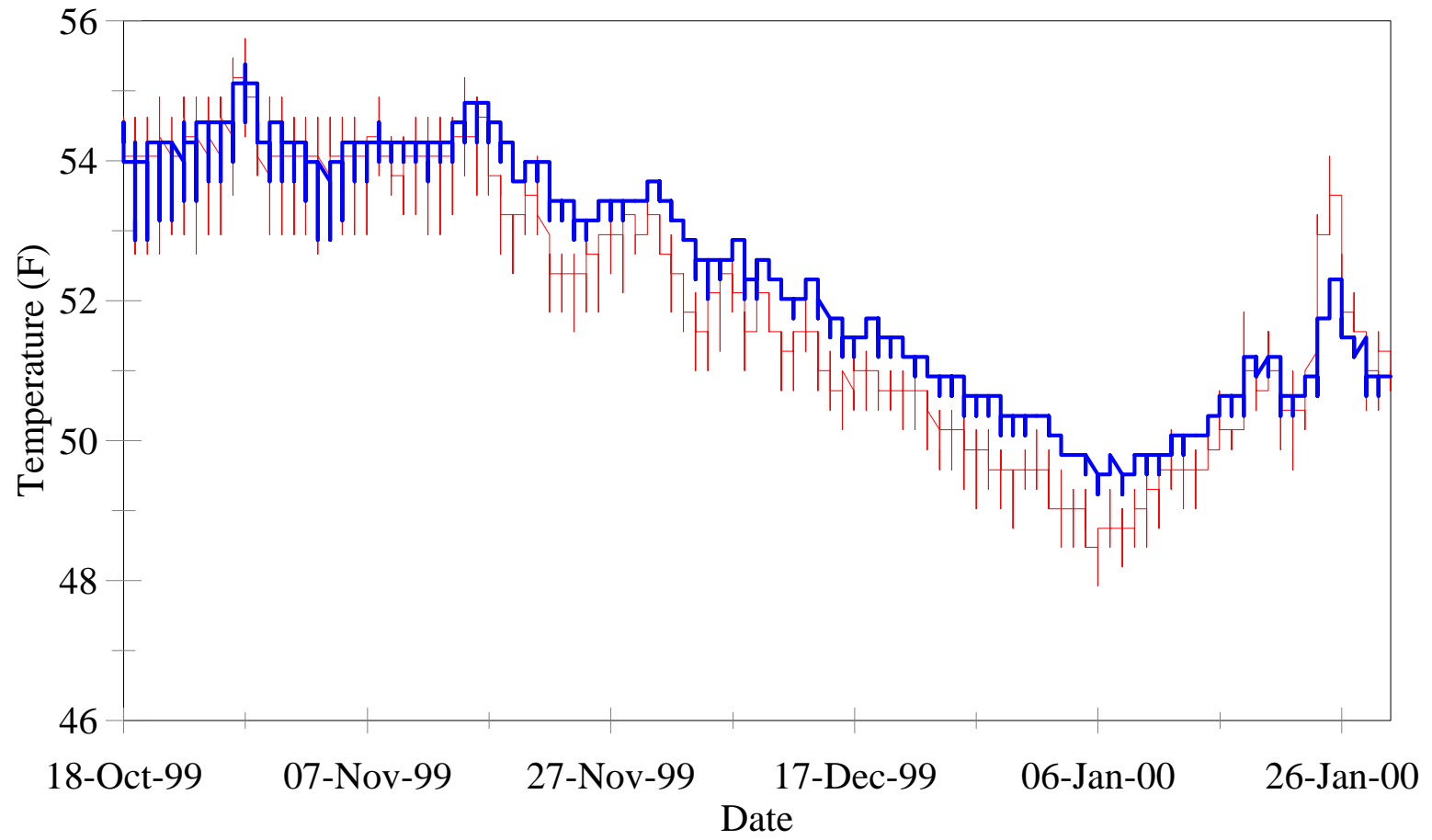
— Surface Temp — Intragravel Temp

R10 P3



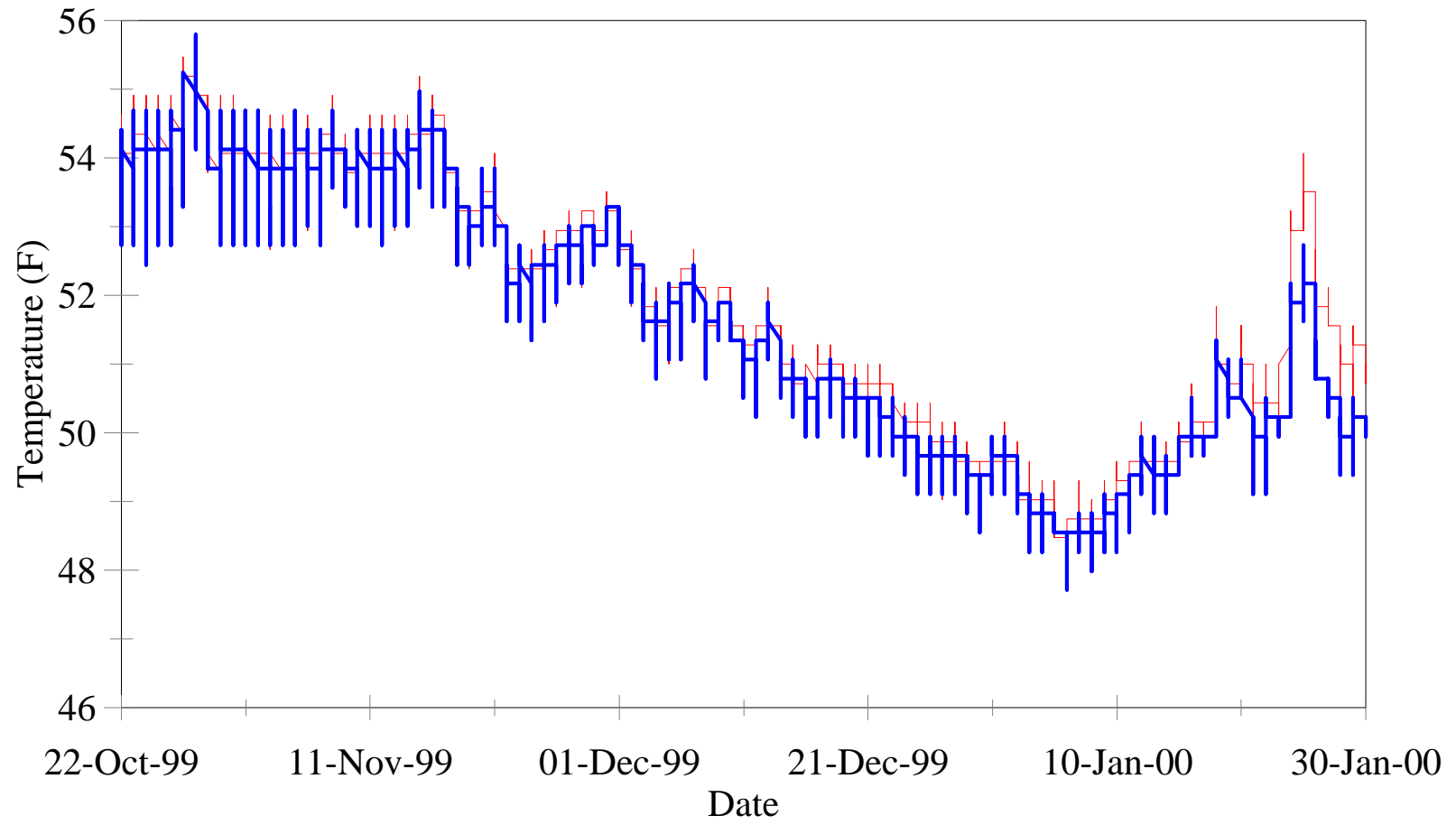
— Surface Temp — Intragravel Temp

R10 P4



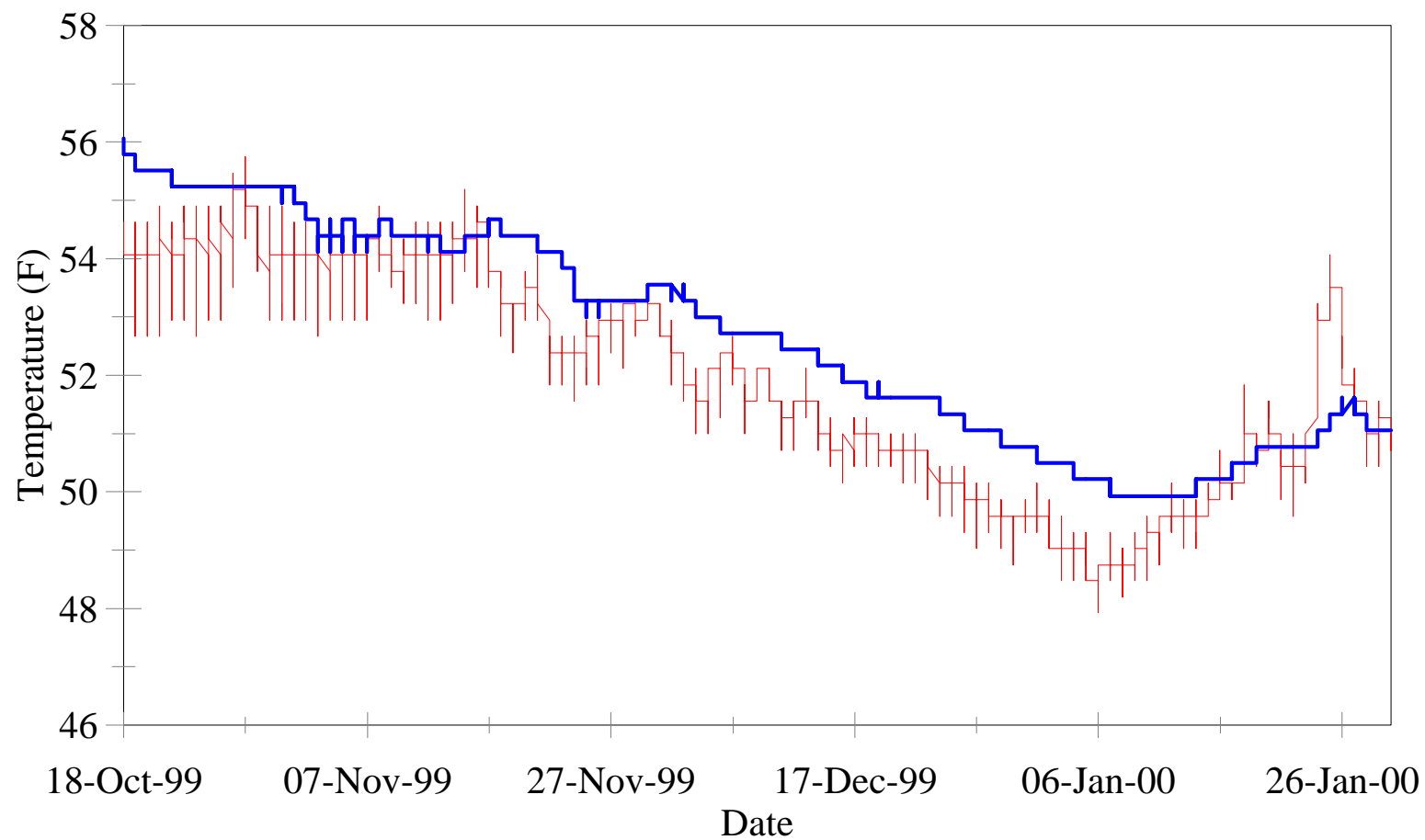
— Surface Temp — Intragravel Temp

R12 P1



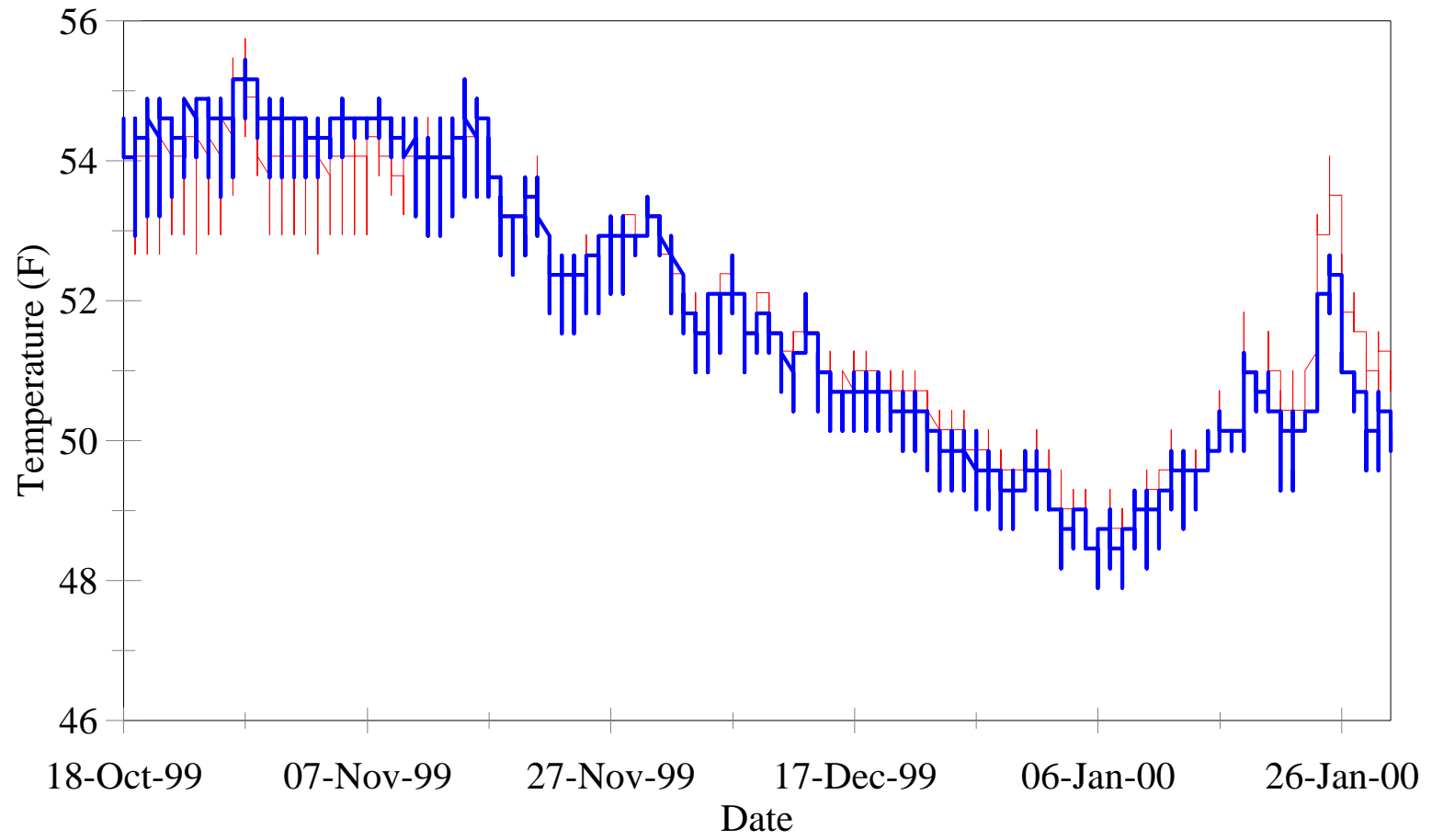
— Surface Temp — Intragravel Temp

R12 P2



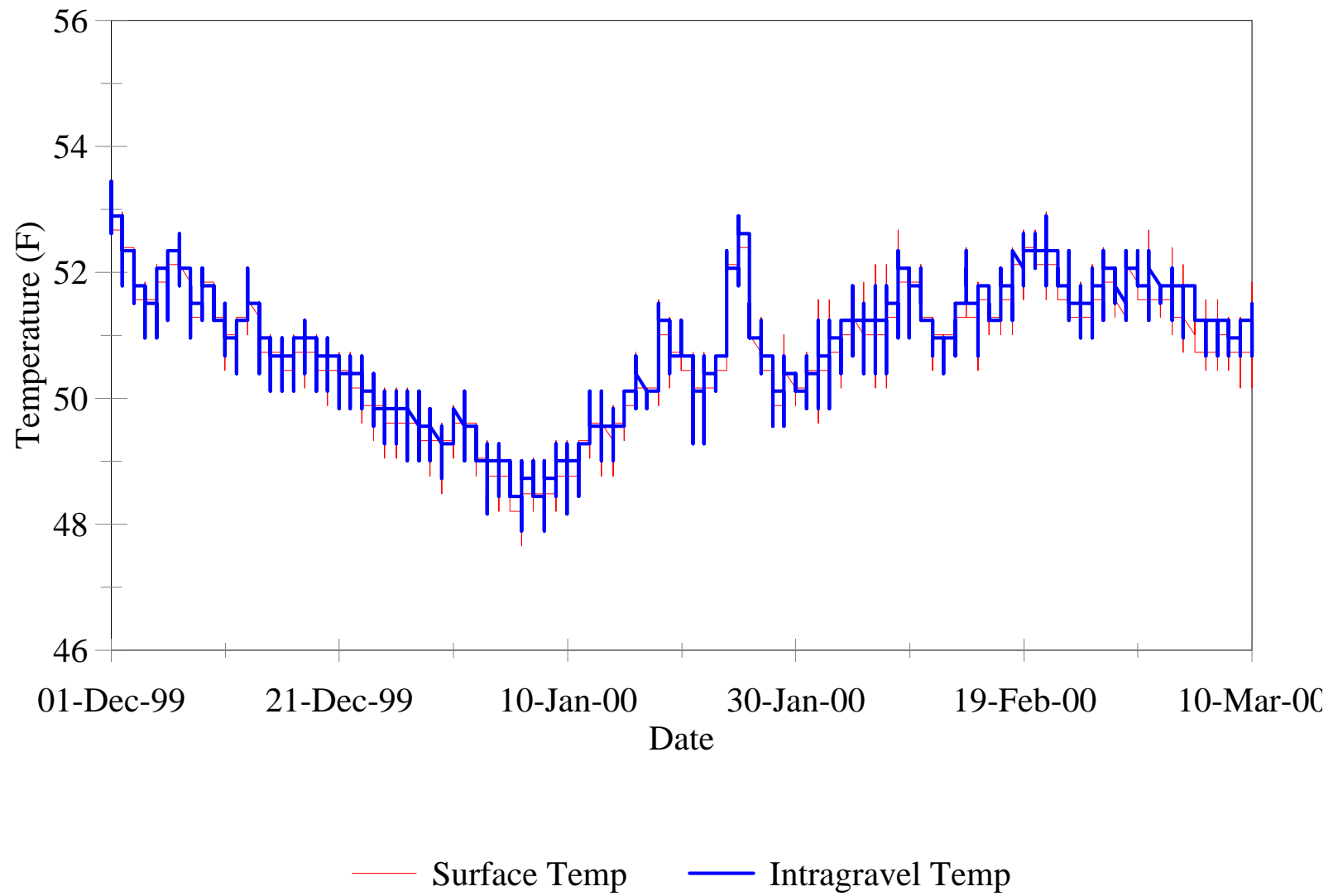
— Surface Temp — Intragravel Temp

R12 P3

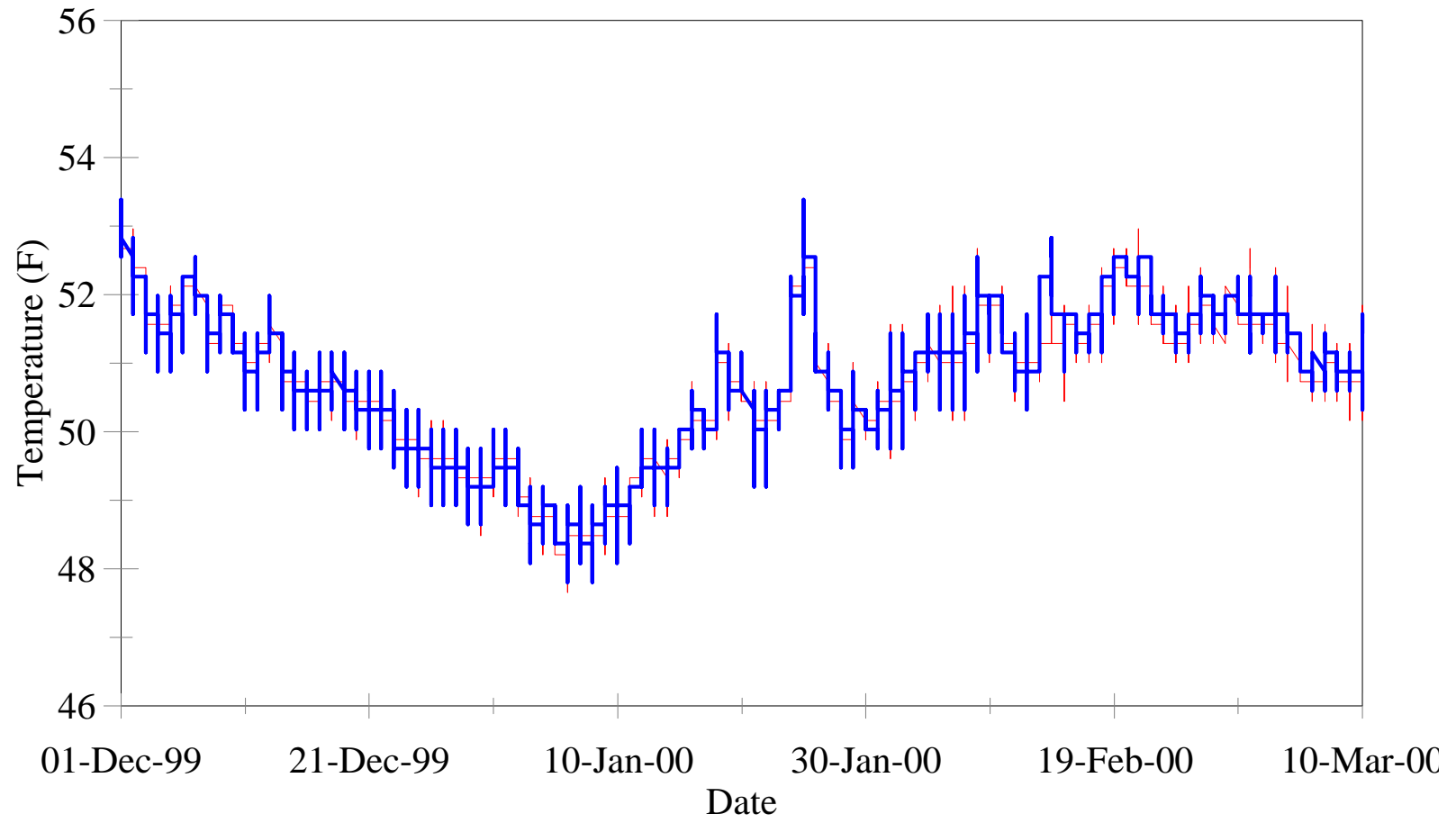


— Surface Temp — Intragravel Temp

R13 P2

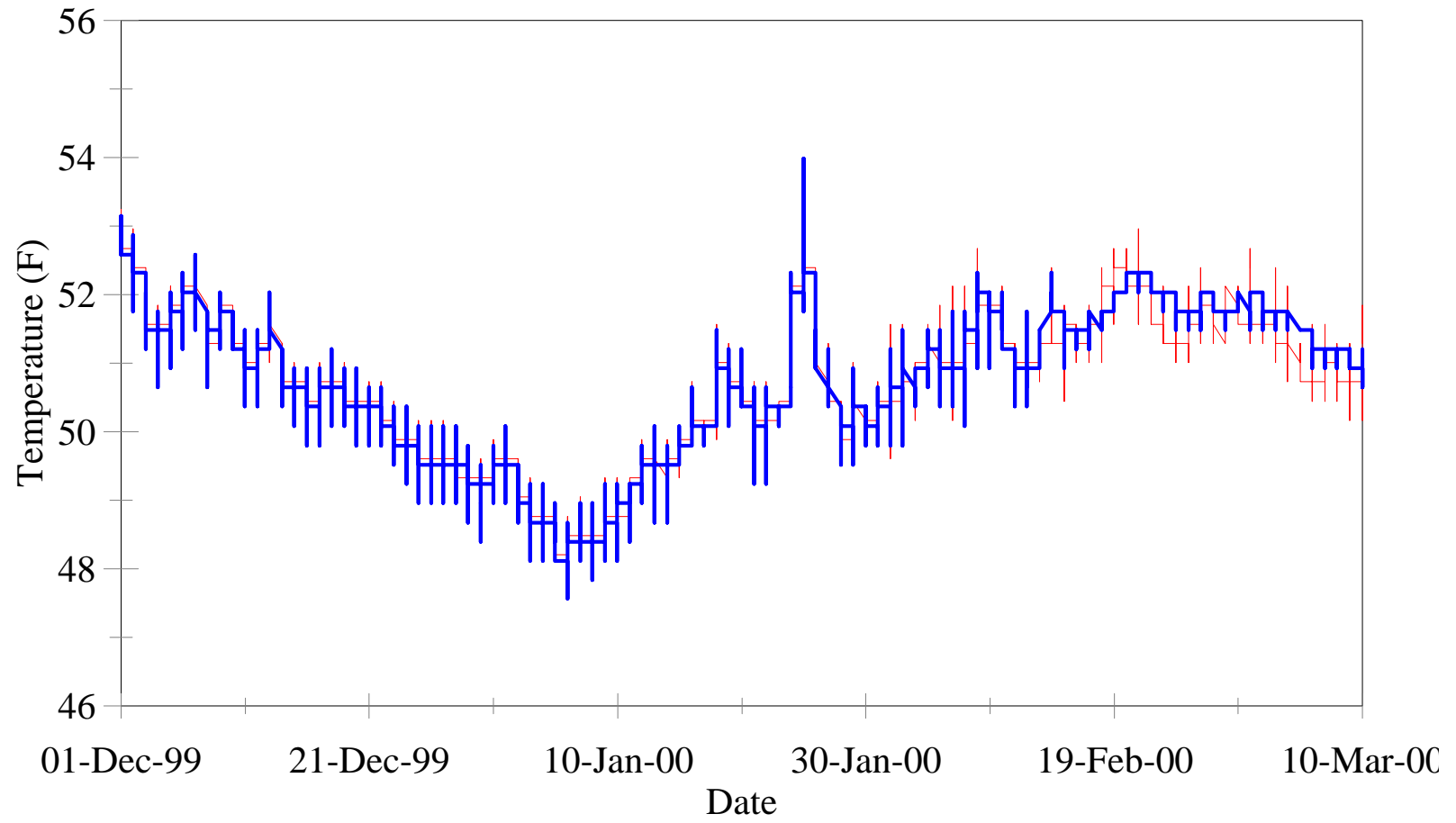


R14 P1



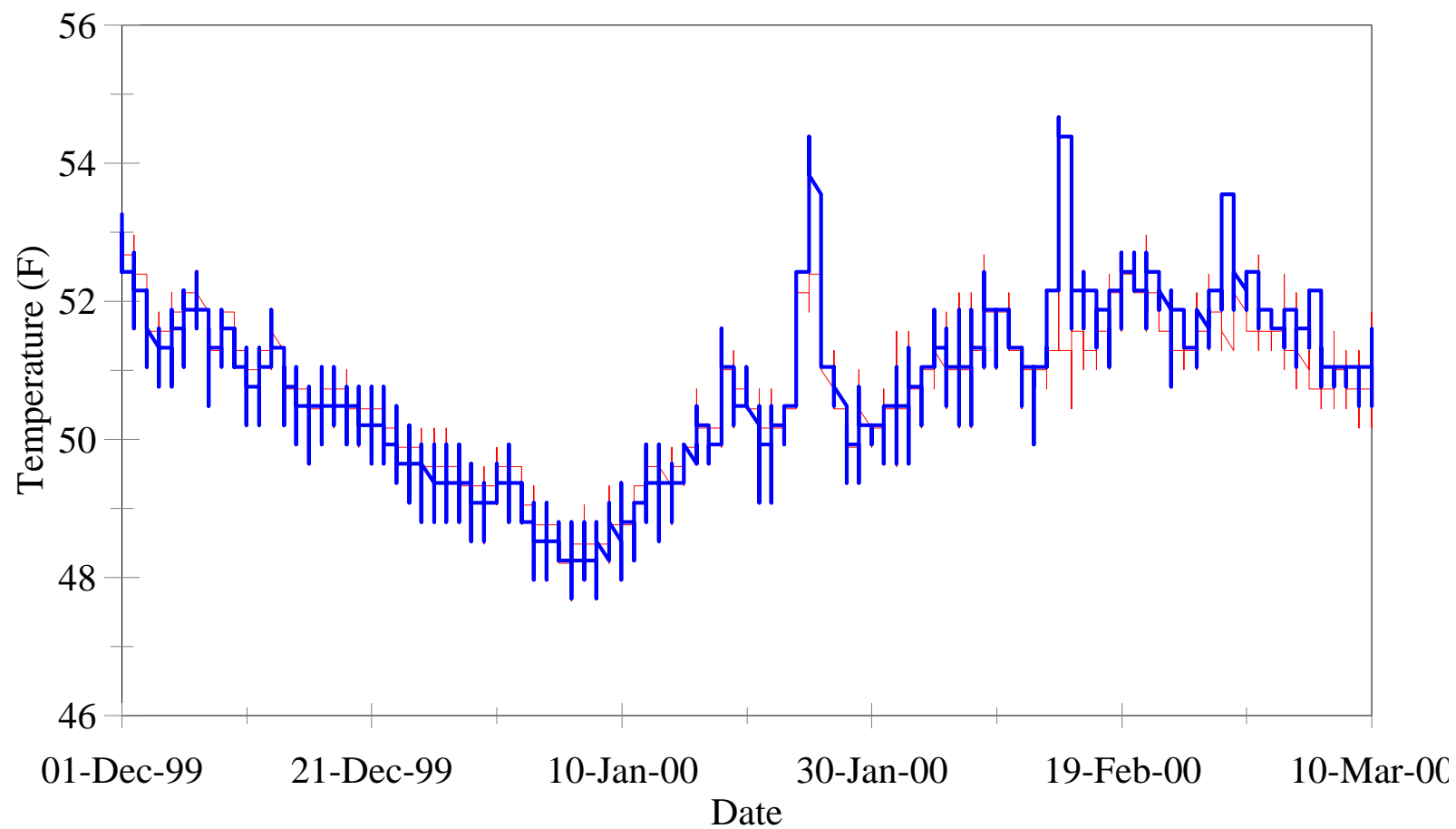
— Surface Temp — Intragravel Temp

R14 P3



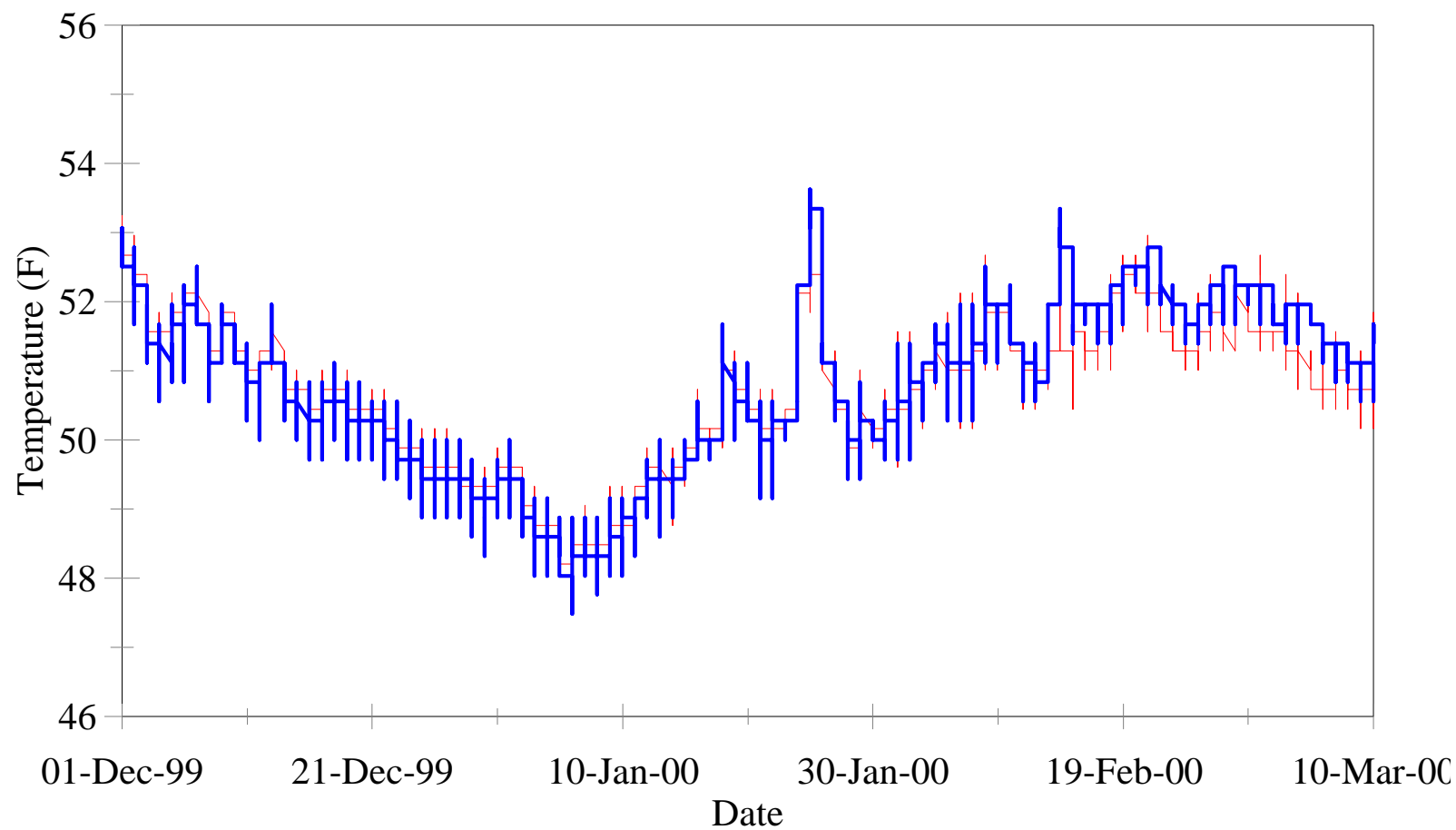
— Surface Temp — Intragravel Temp

R14A P1



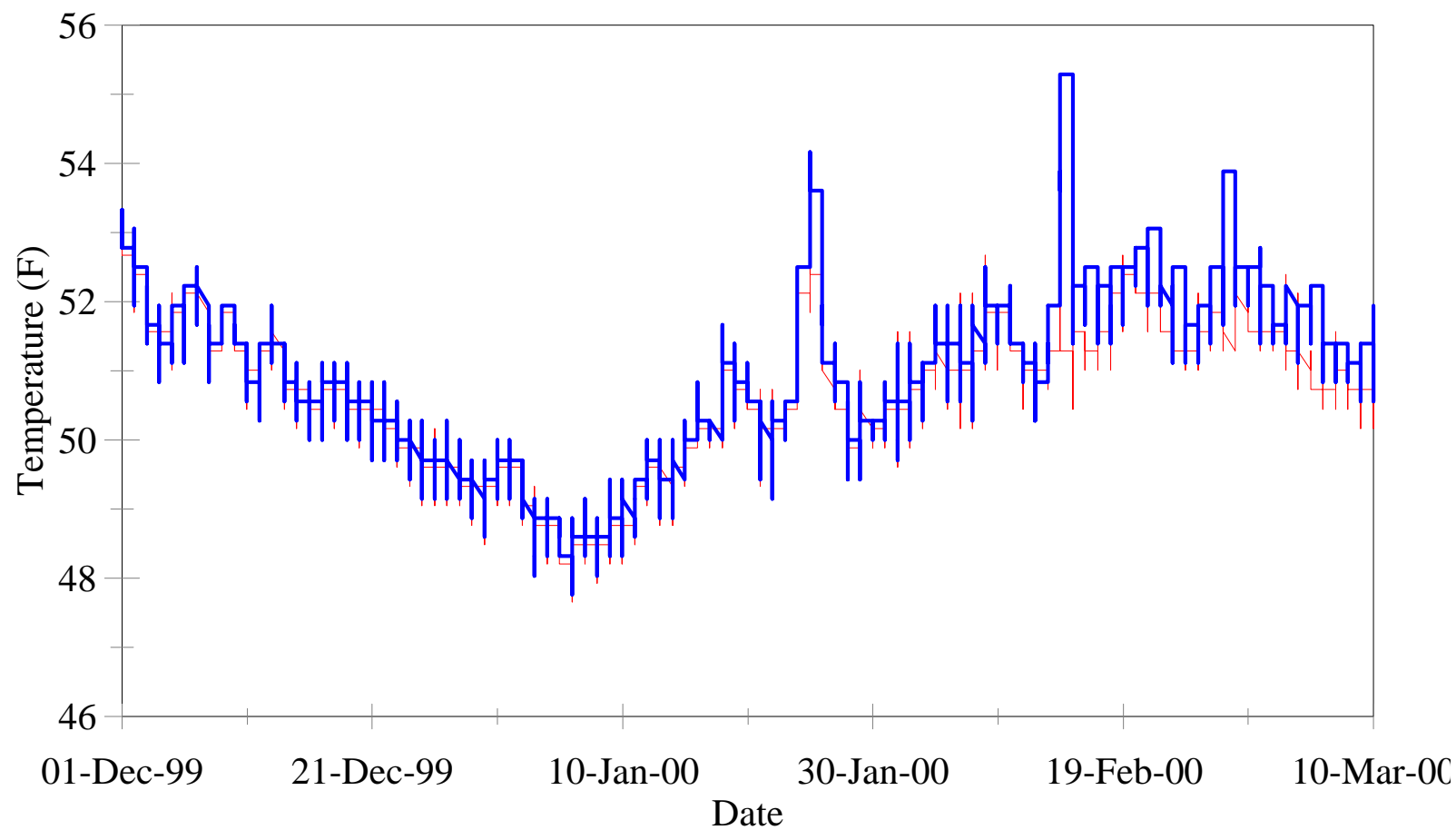
— Surface Temp — Intragravel Temp

R14A P2



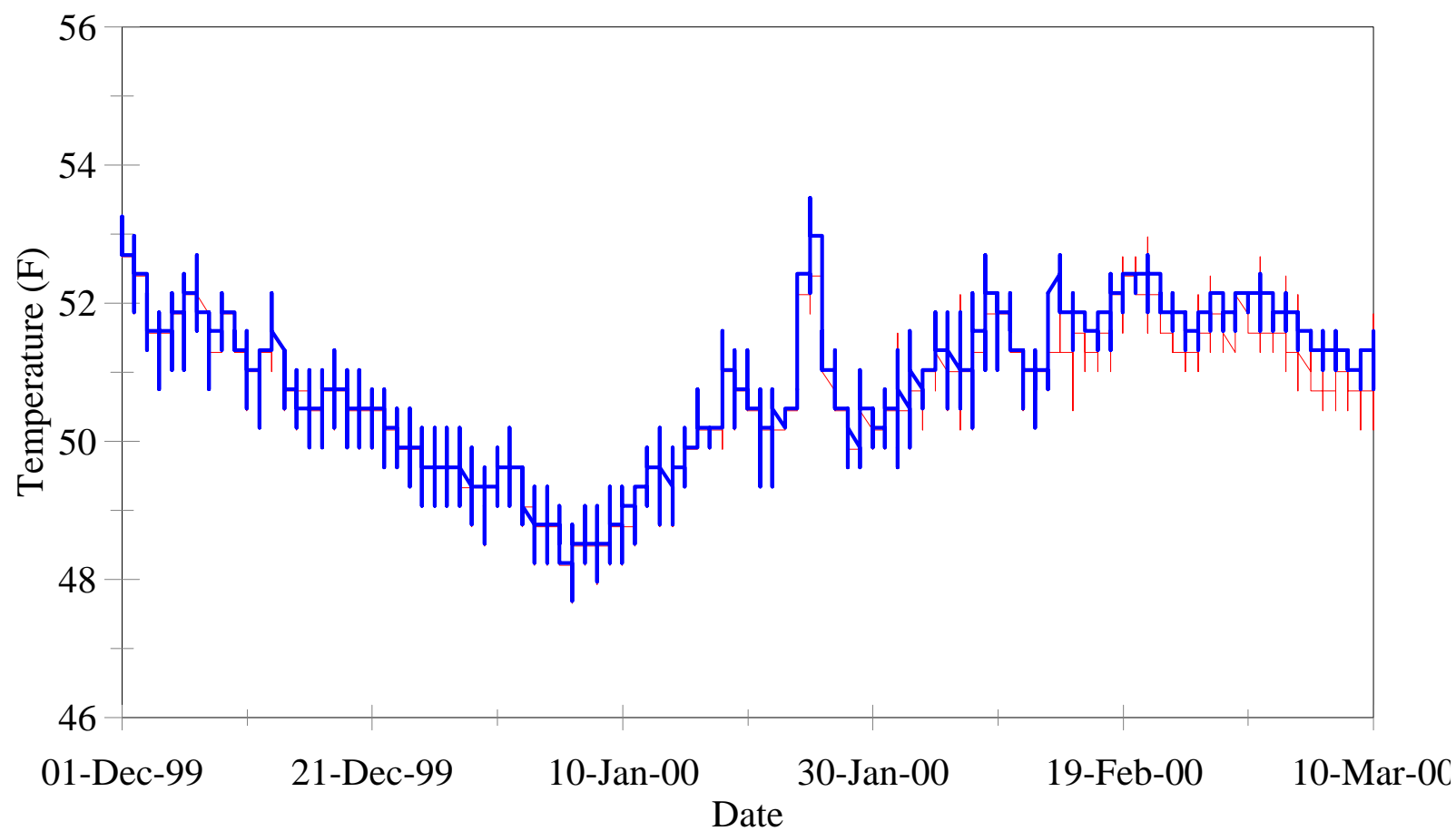
— Surface Temp — Intragravel Temp

R14A P3



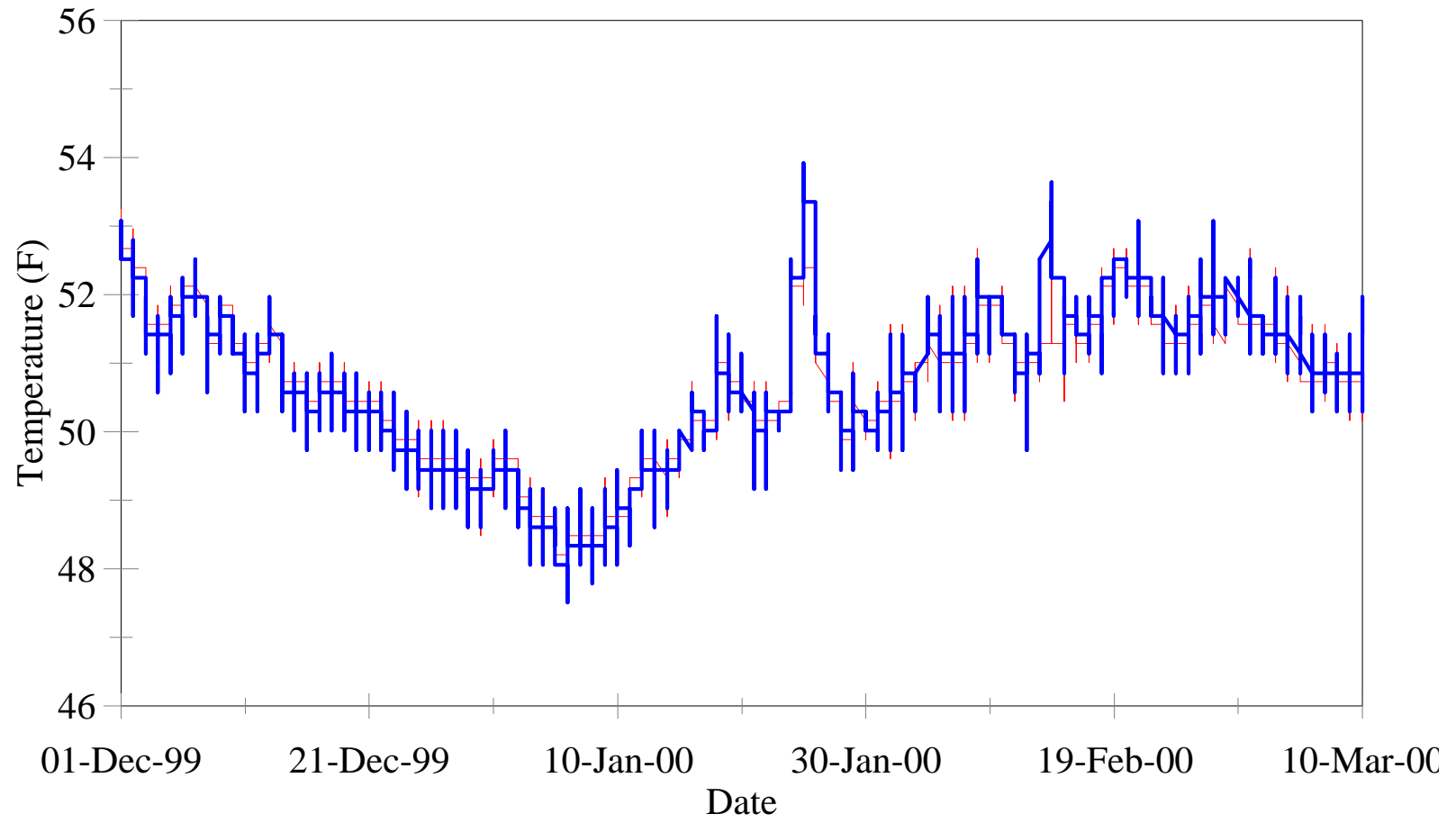
— Surface Temp — Intragravel Temp

R14A P4



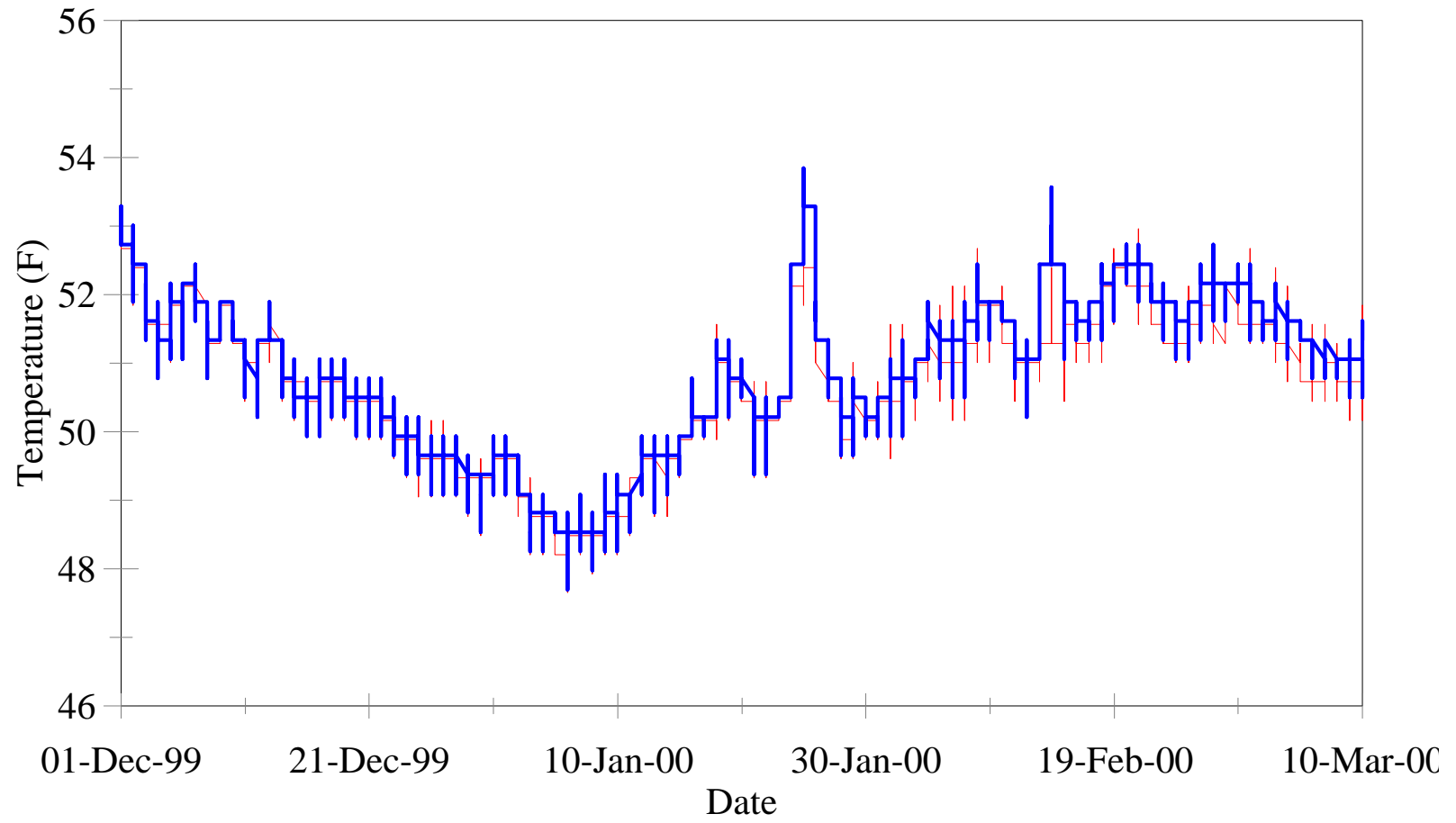
— Surface Temp — Intragravel Temp

R15 P1



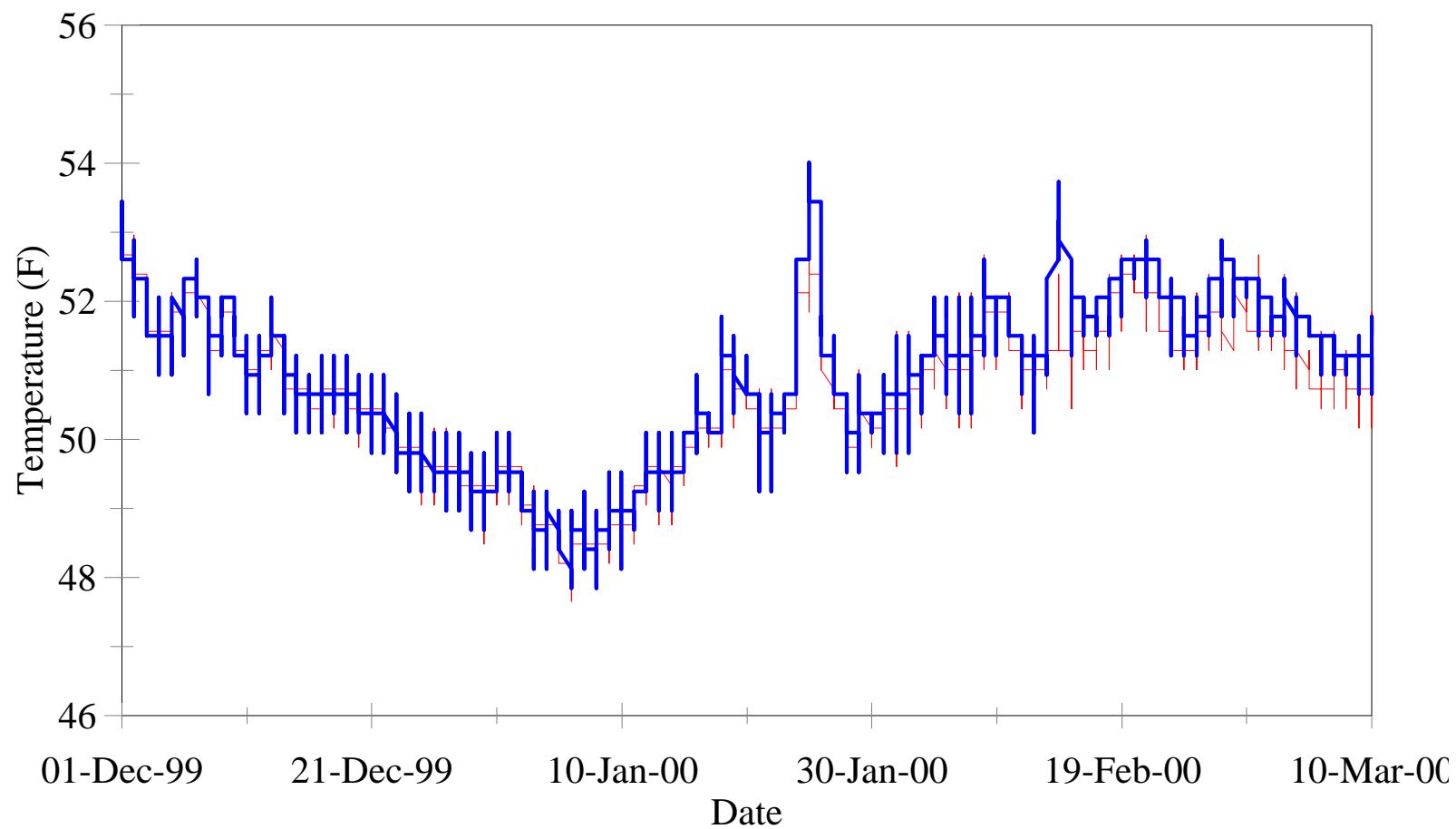
— Surface Temp — Intragravel Temp

R16 P1



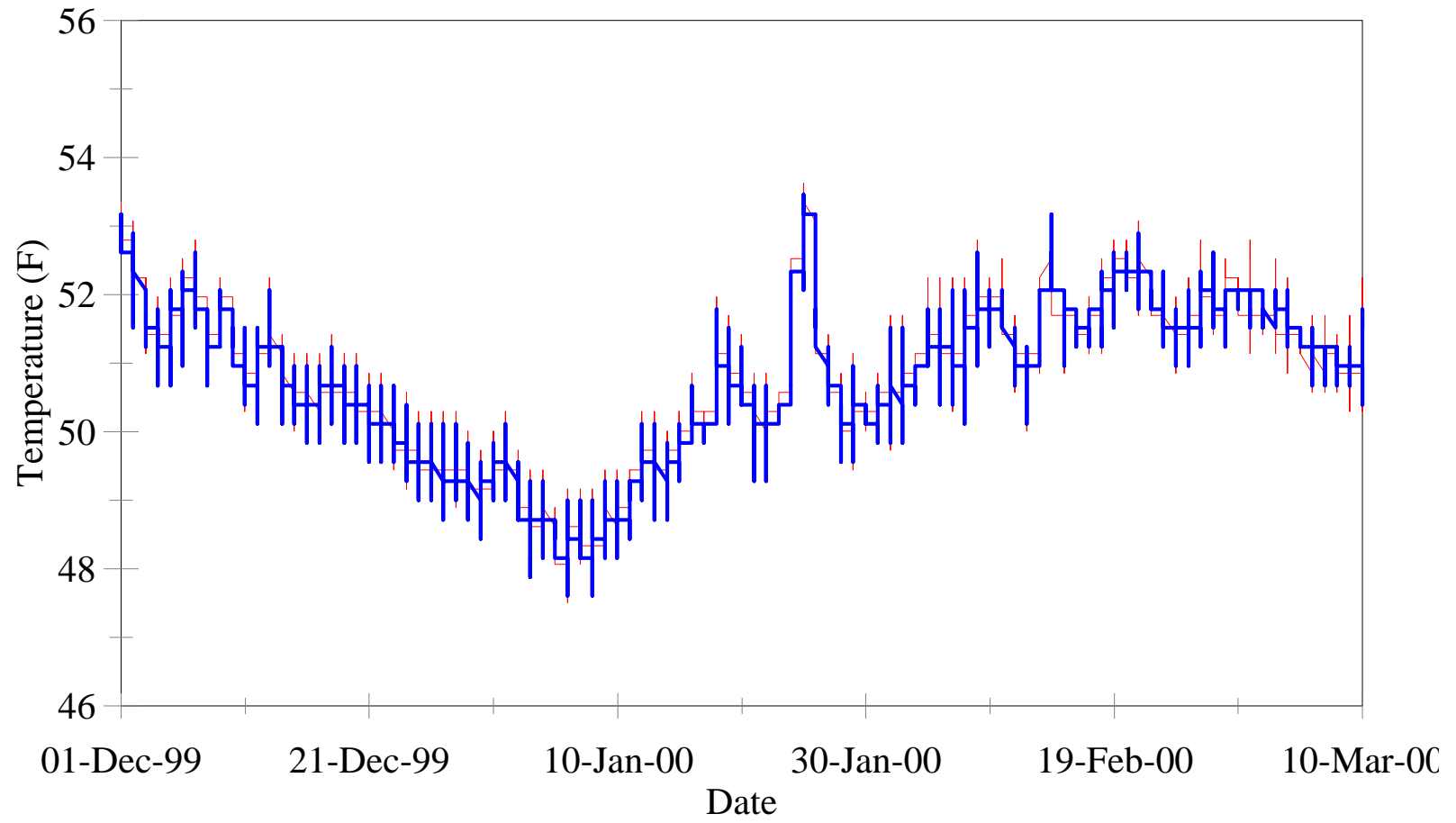
— Surface Temp — Intragravel Temp

R16 P3



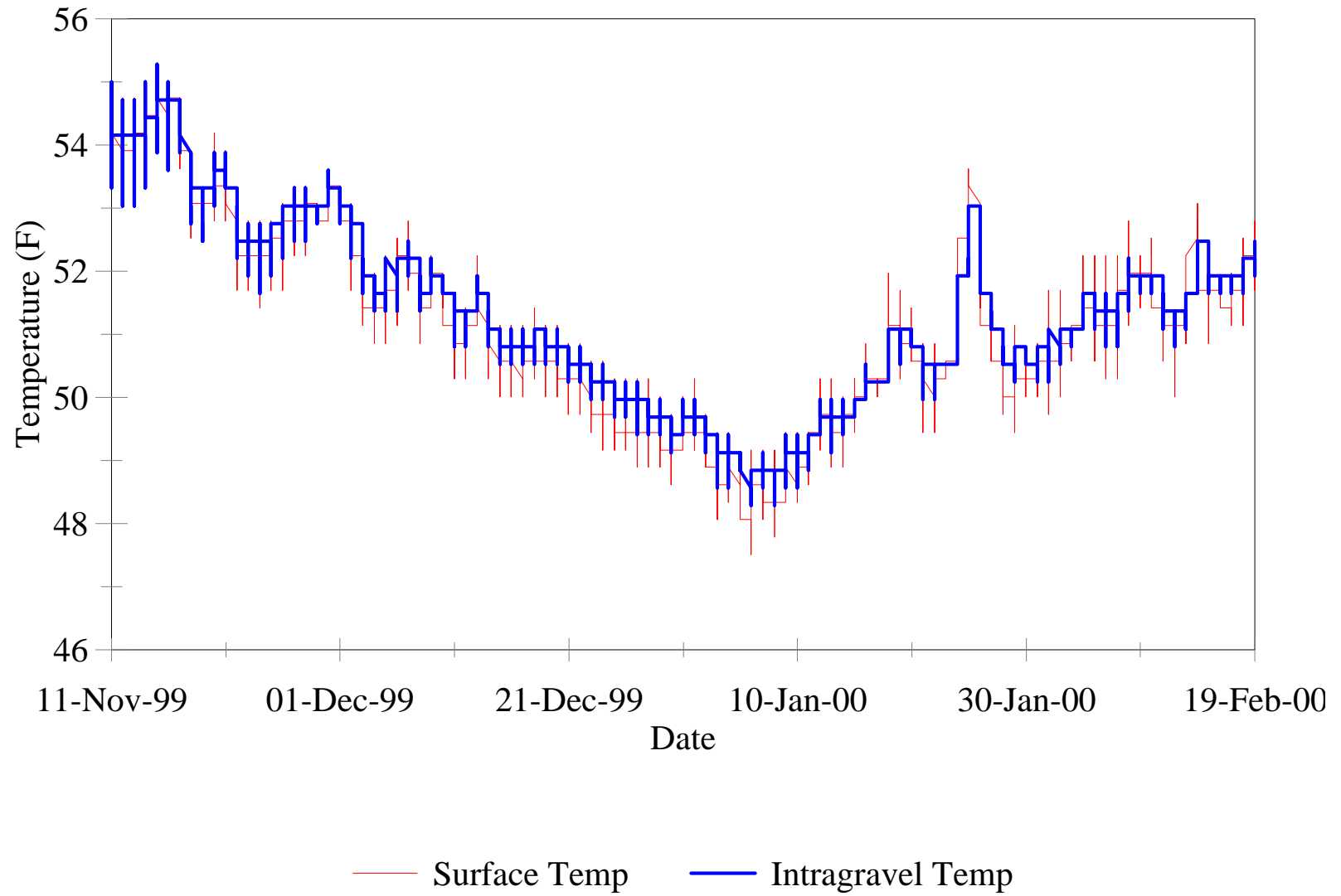
— Surface Temp — Intragravel Temp

R19 P1

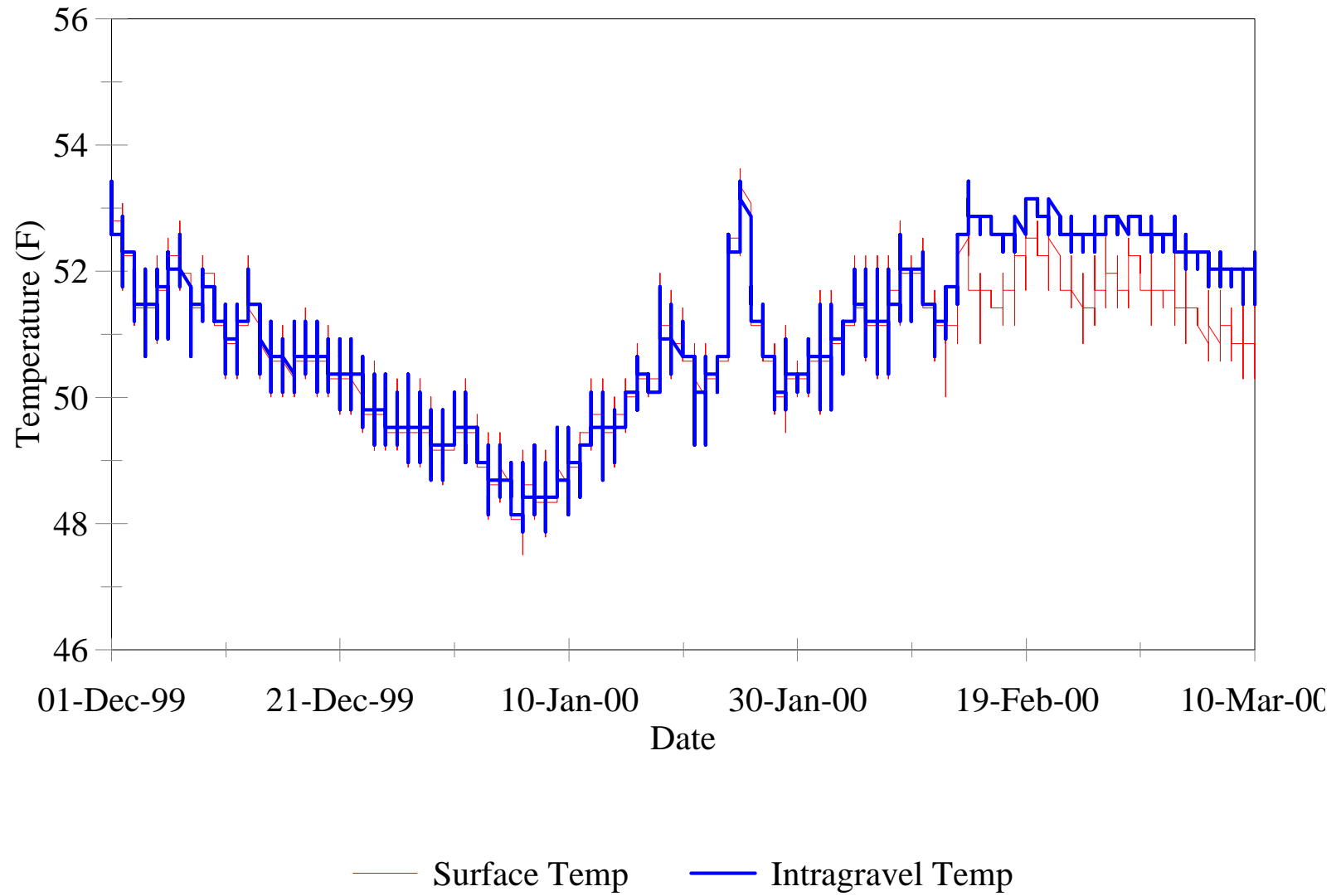


— Surface Temp — Intragravel Temp

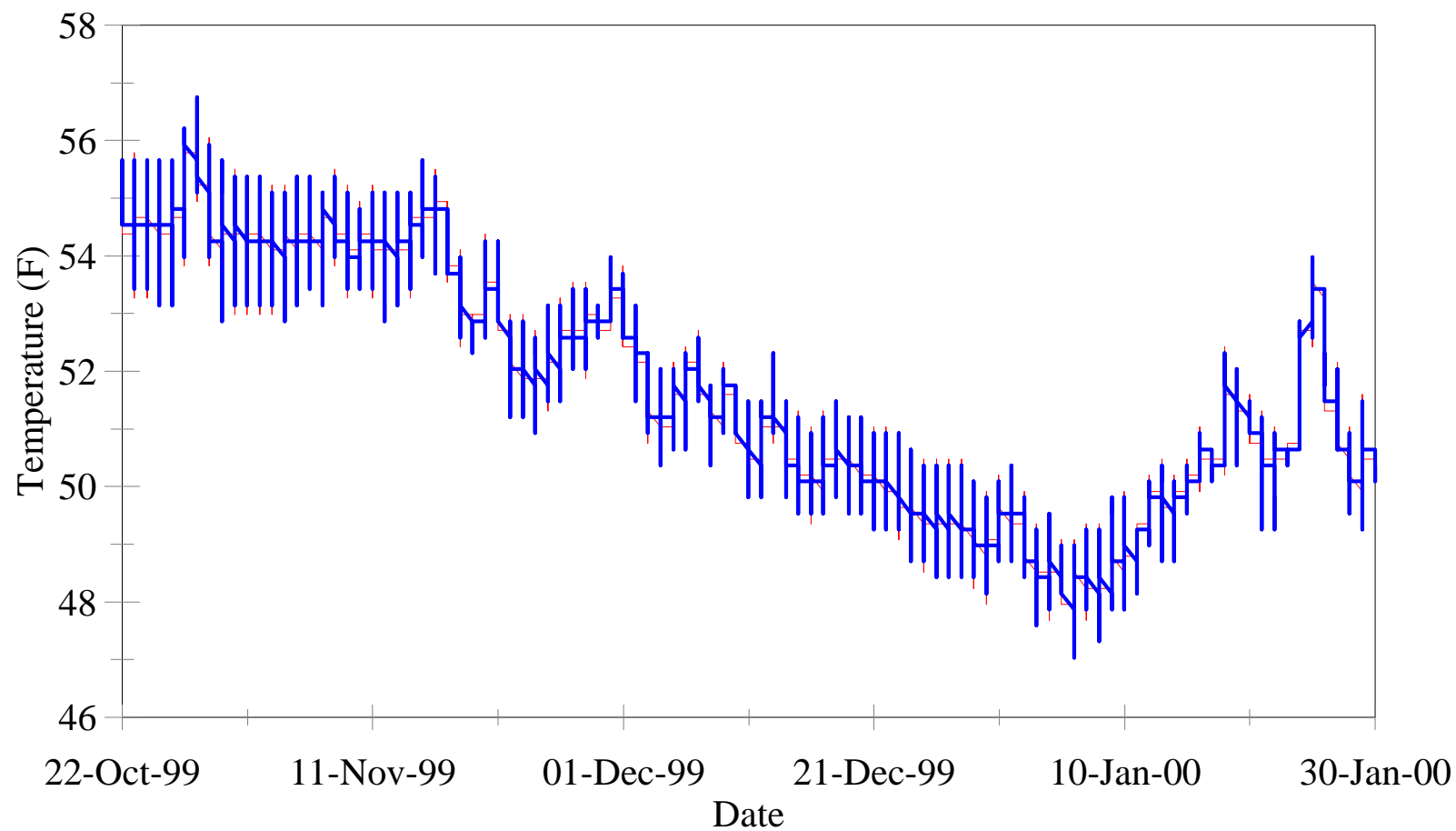
R19 P2



R19 P4

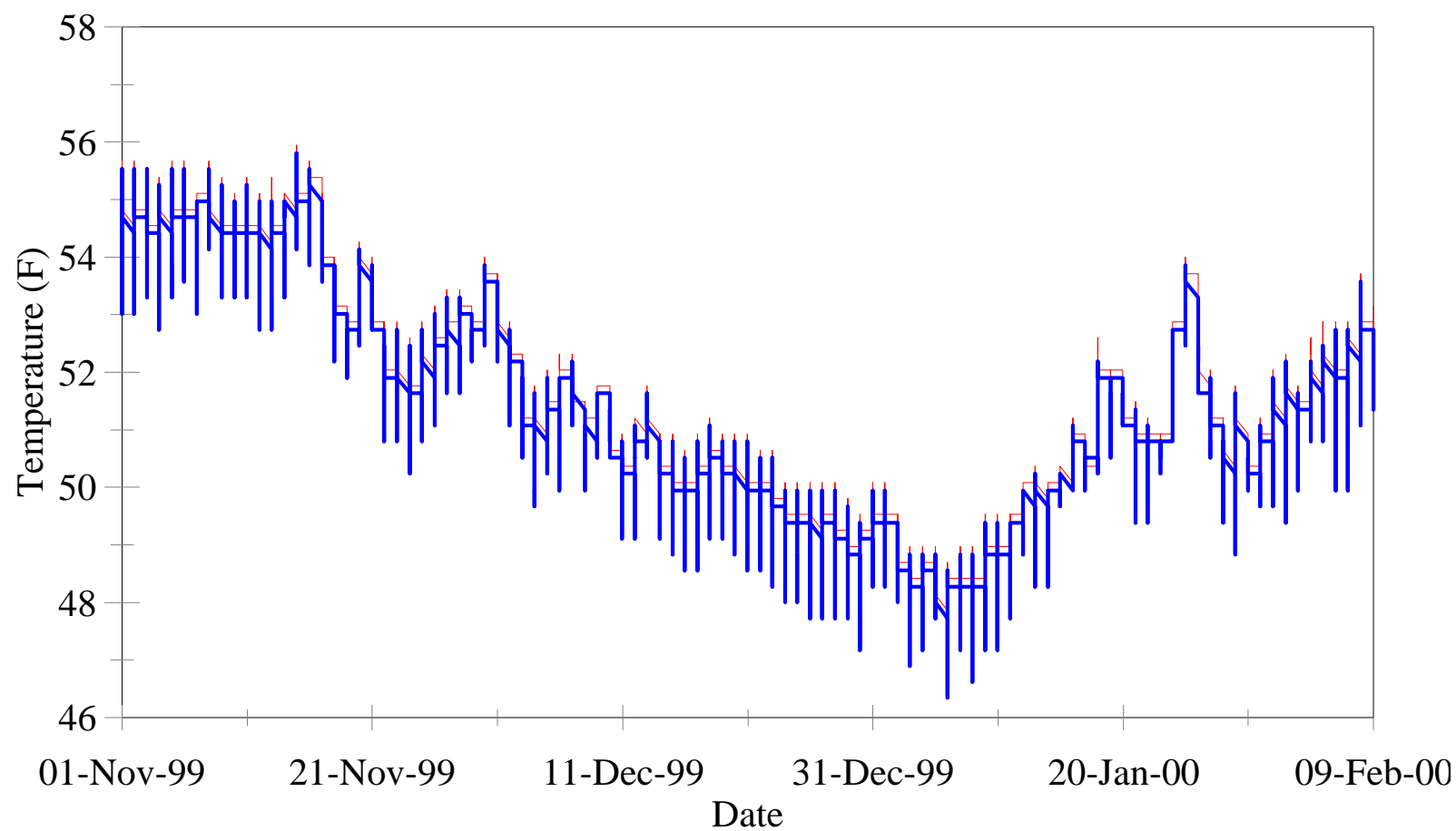


R28A P2



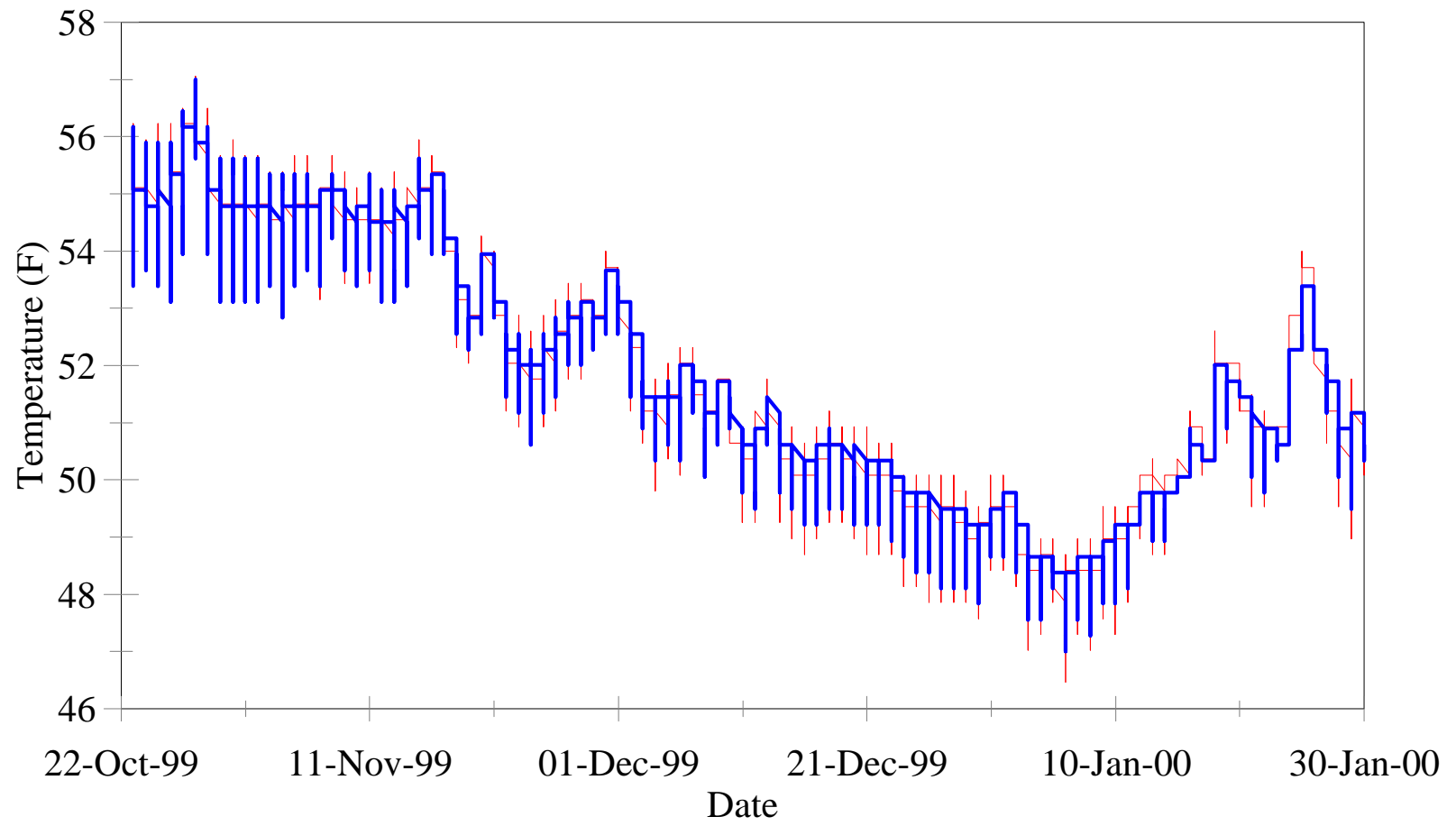
— Surface Temp — Intragravel Temp

R43 P1



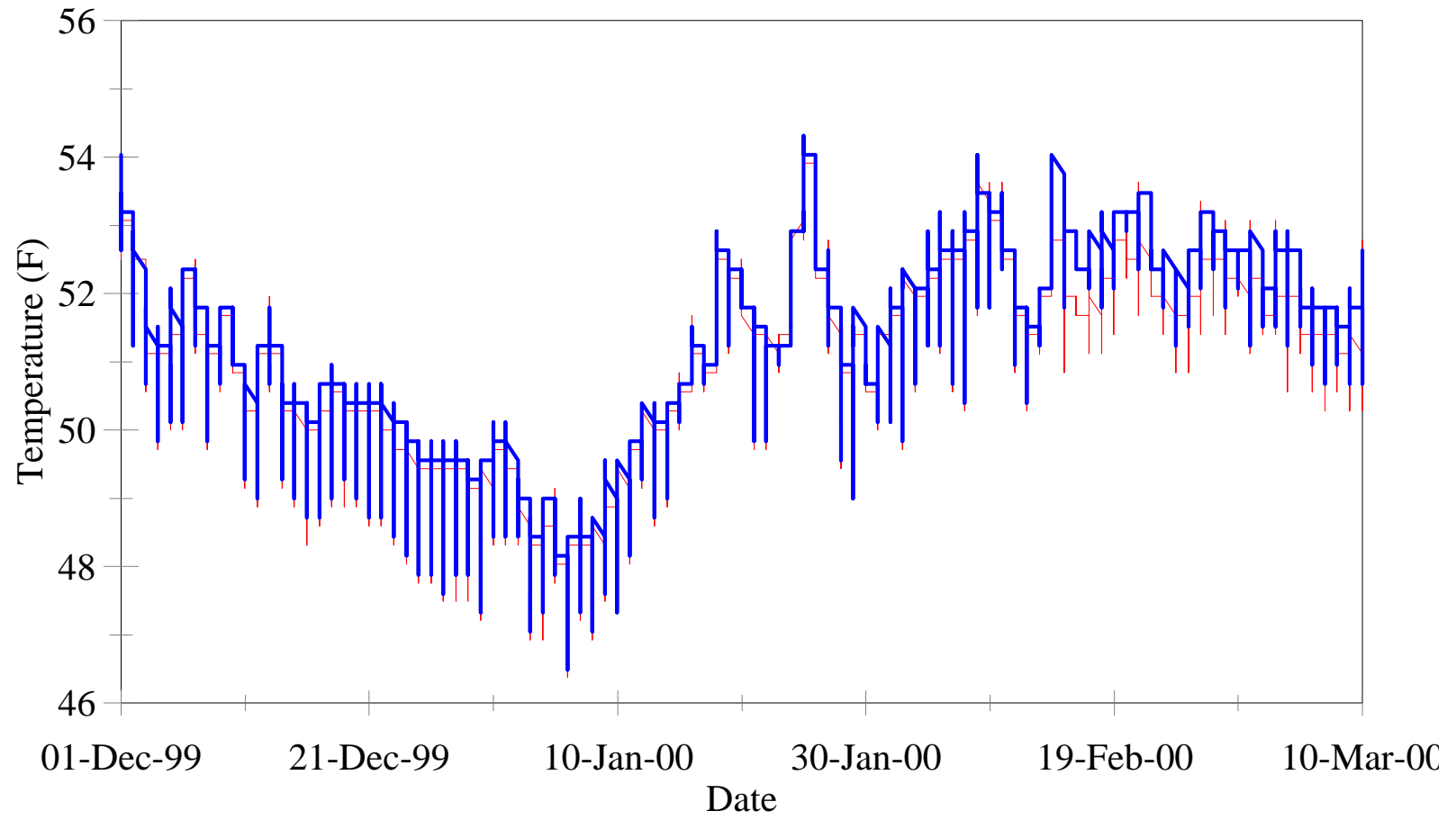
— Surface Temp — Intragravel Temp

R43 P4



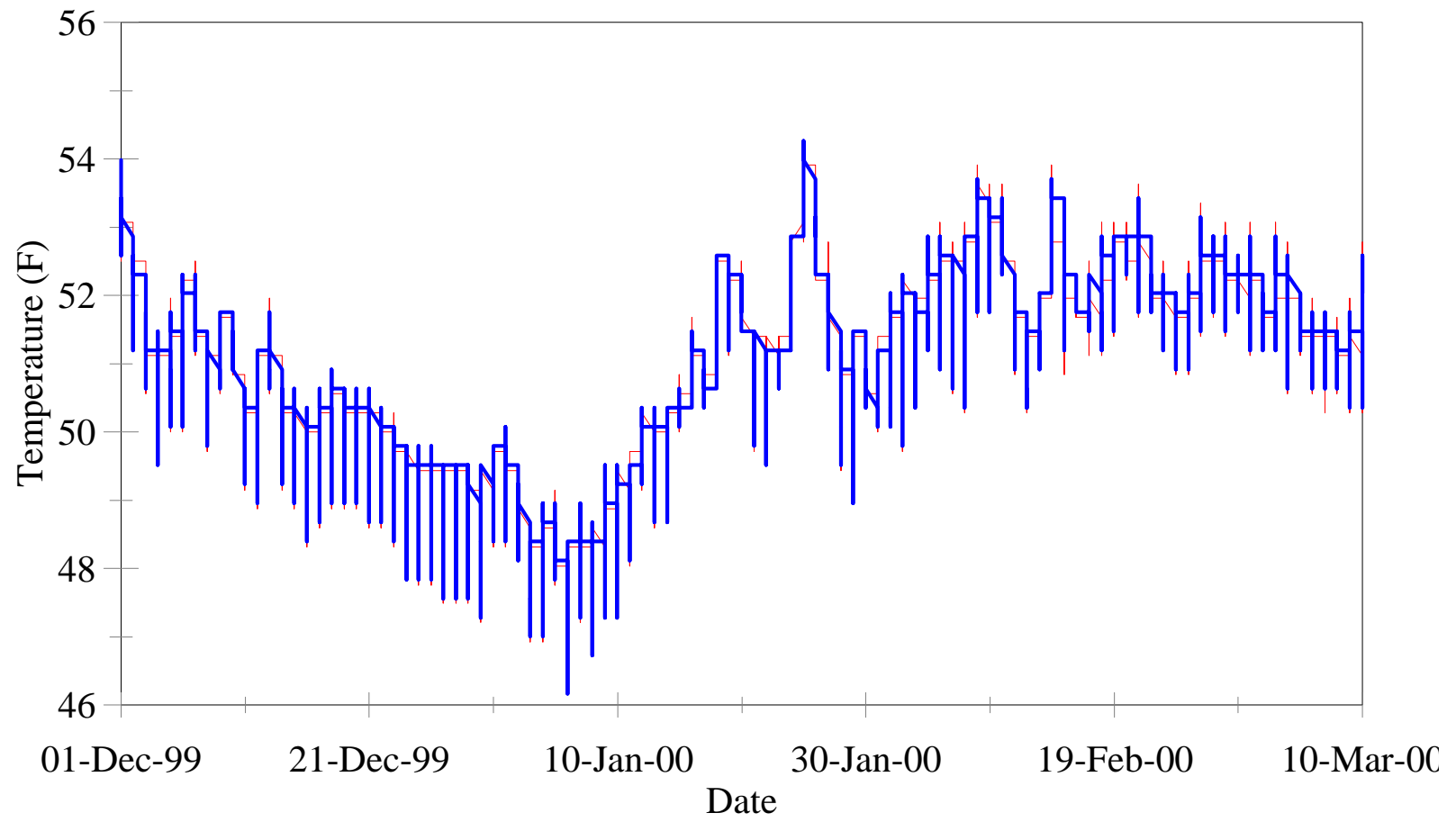
— Surface Temp — Intragravel Temp

R57 P1



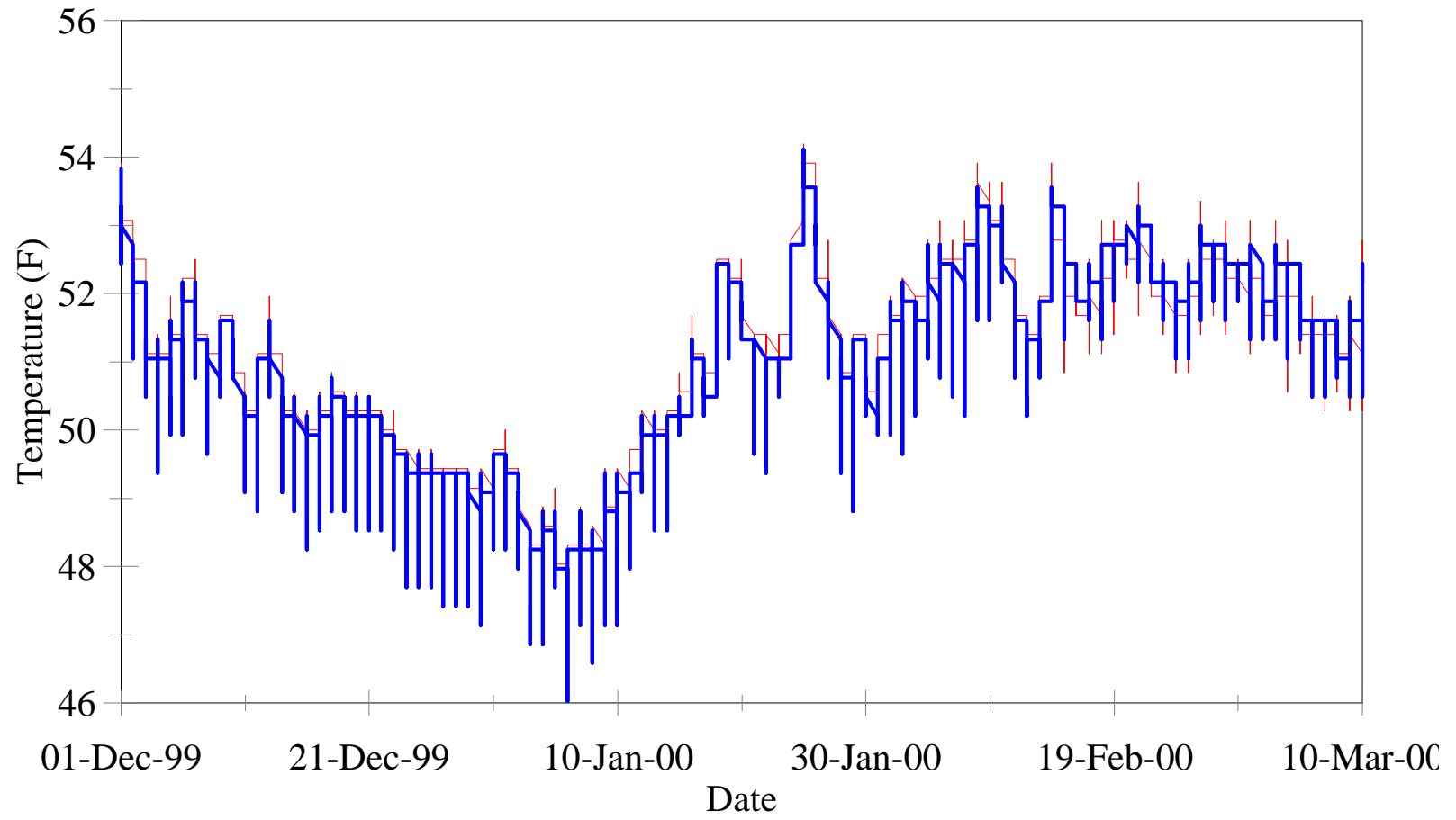
— Surface Temp — Intragravel Temp

R57 P2



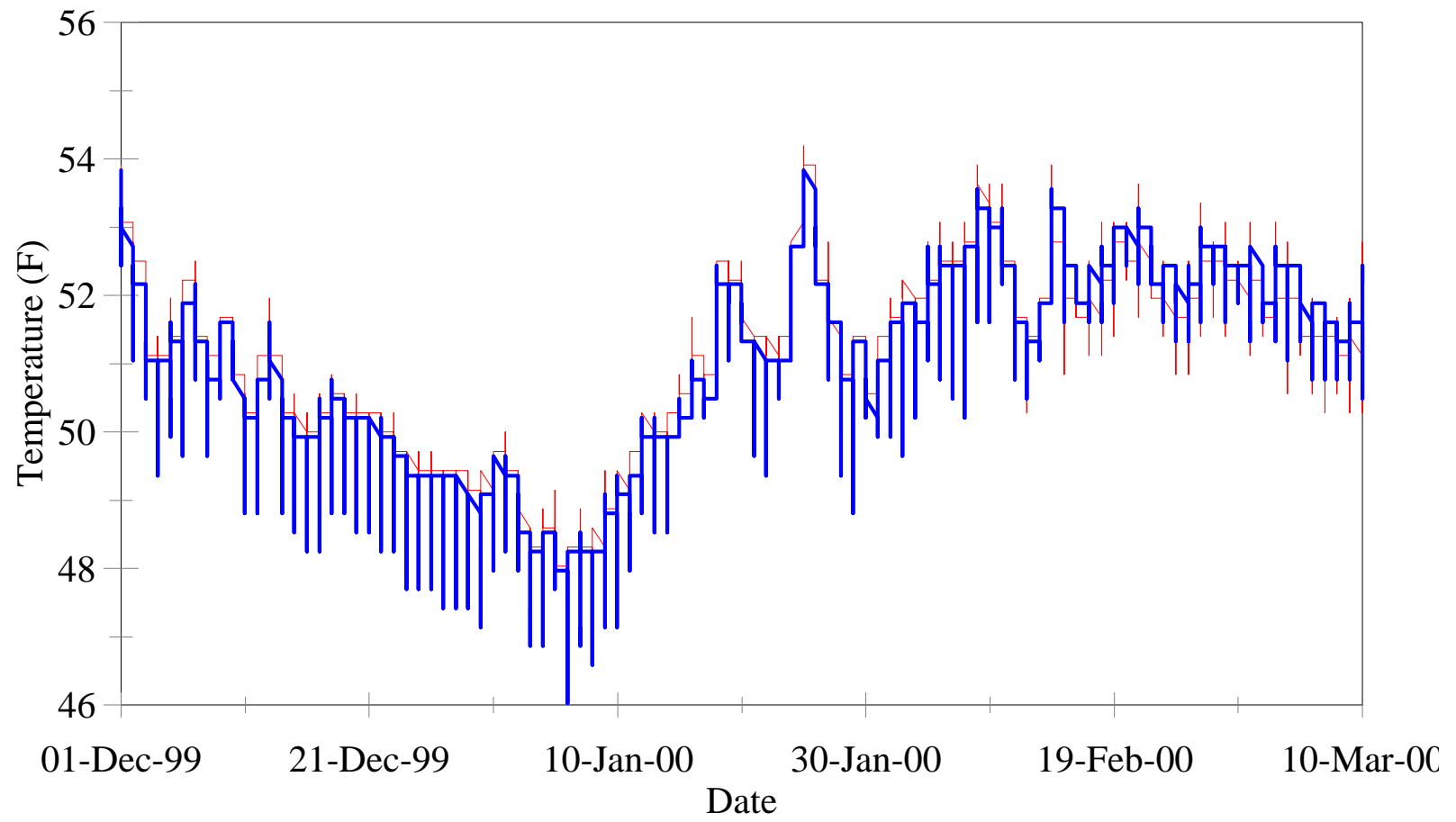
— Surface Temp — Intragravel Temp

R57 P3



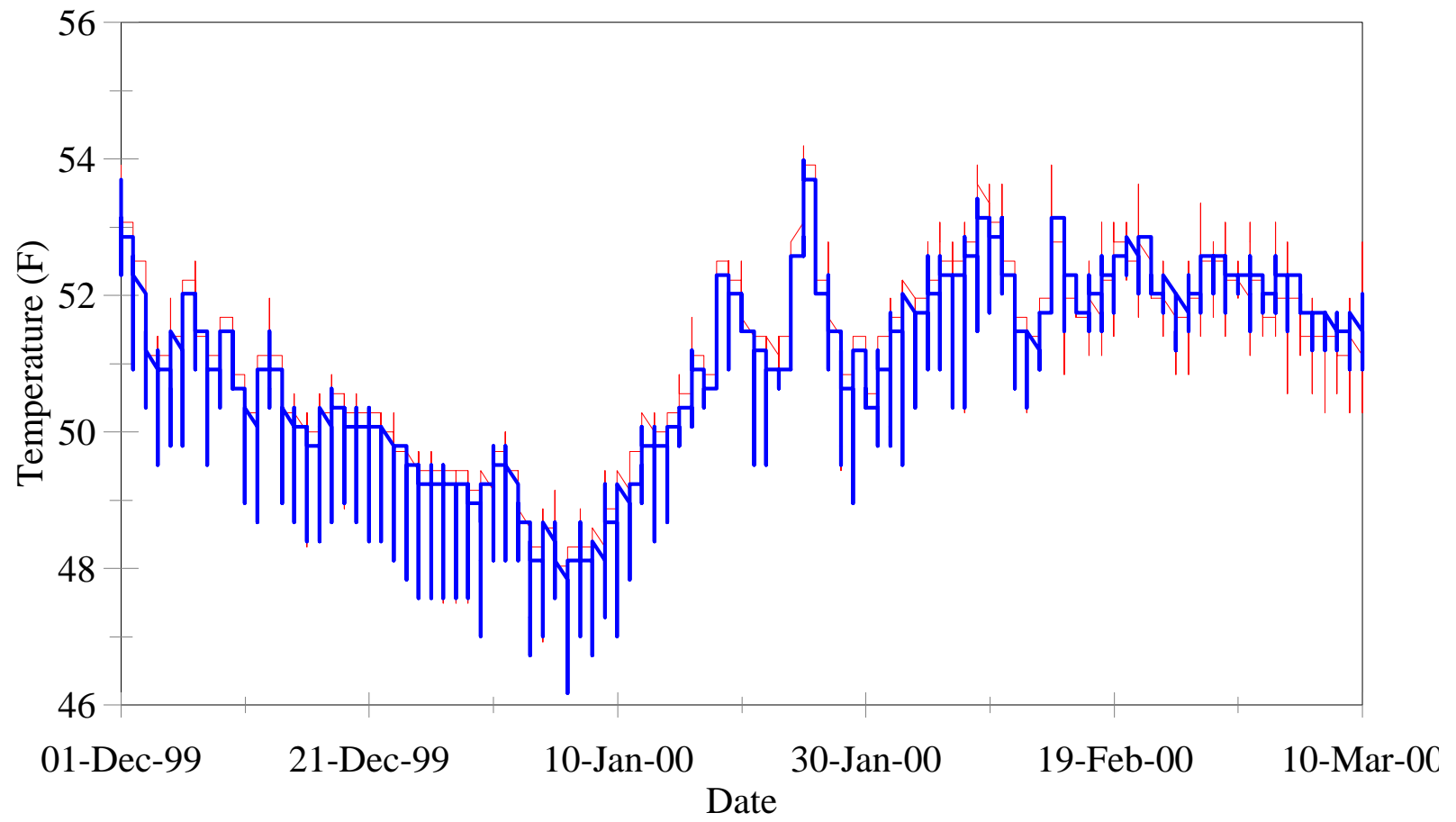
— Surface Temp — Intragravel Temp

R58 P1



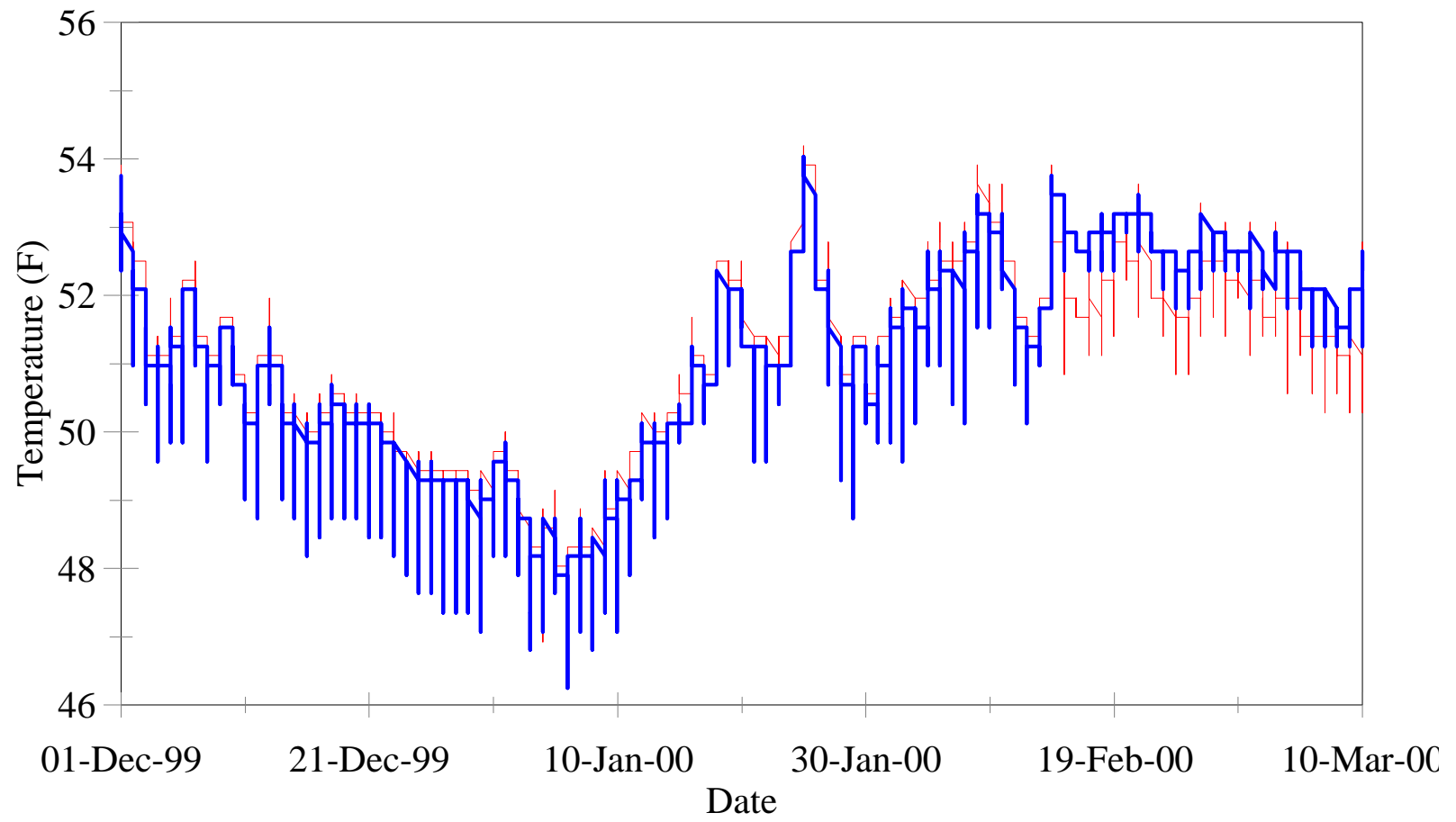
— Surface Temp — Intragravel Temp

R58 P2



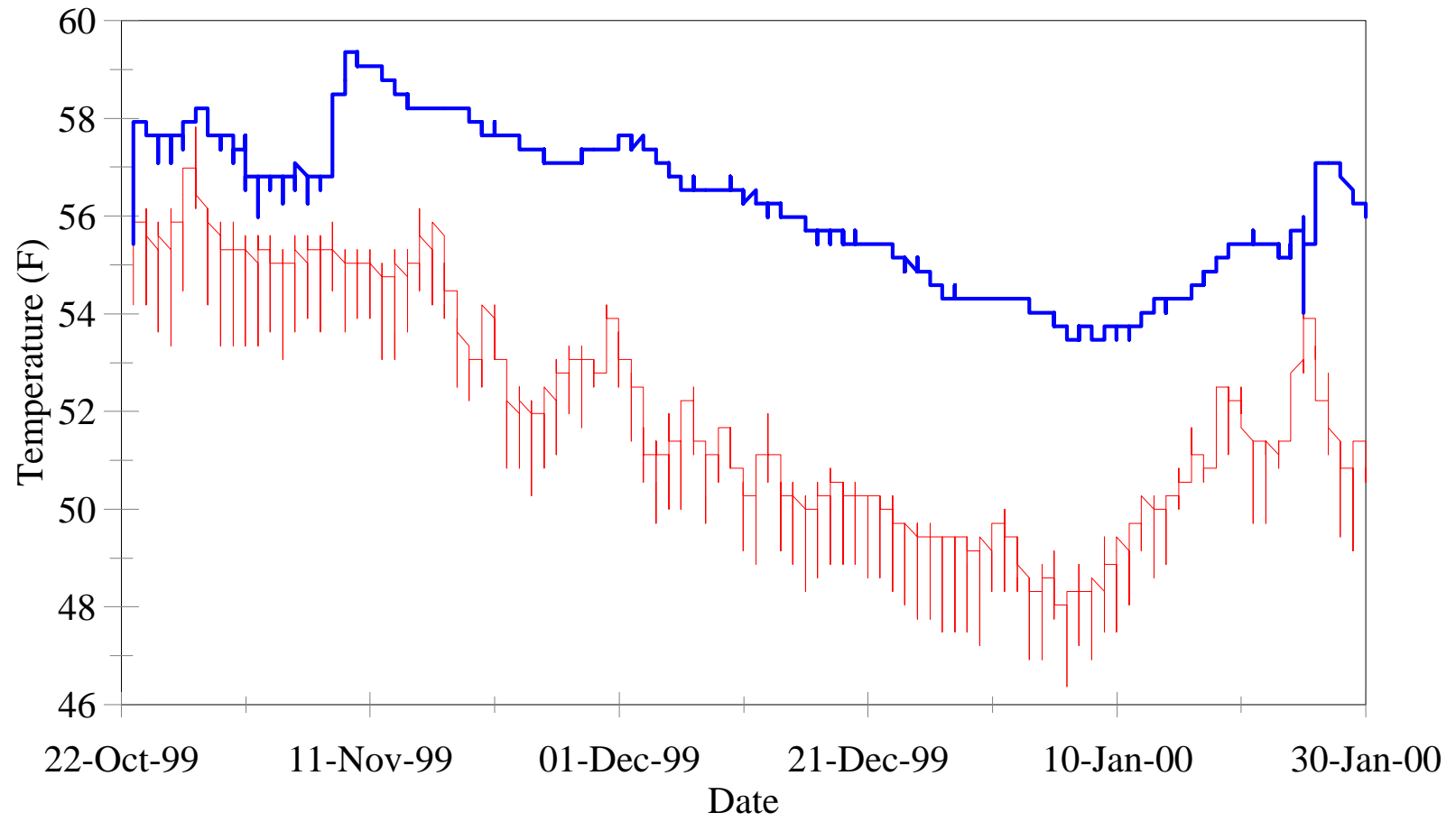
— Surface Temp — Intragravel Temp

R58 P3



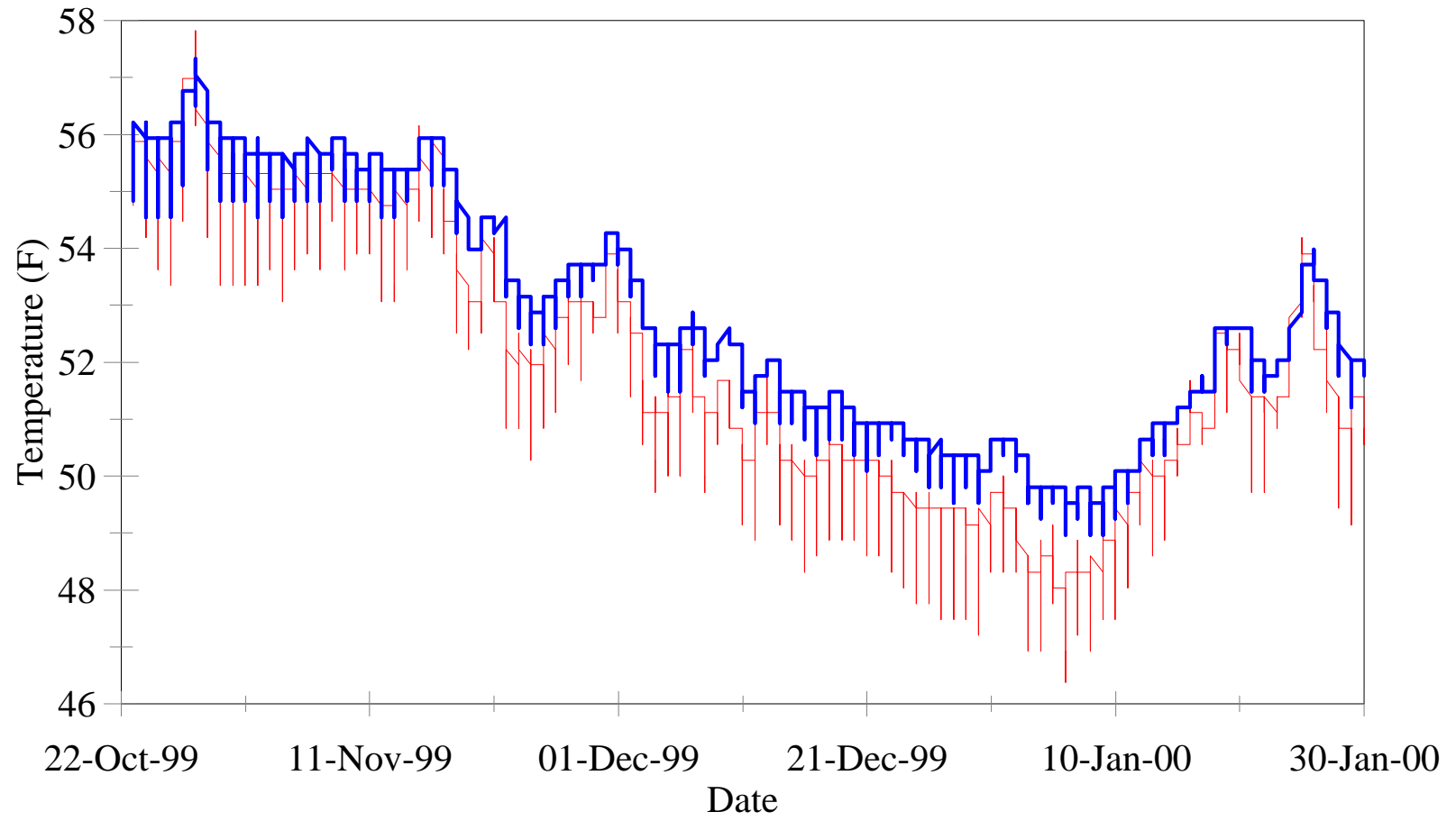
— Surface Temp — Intragravel Temp

R58 P4



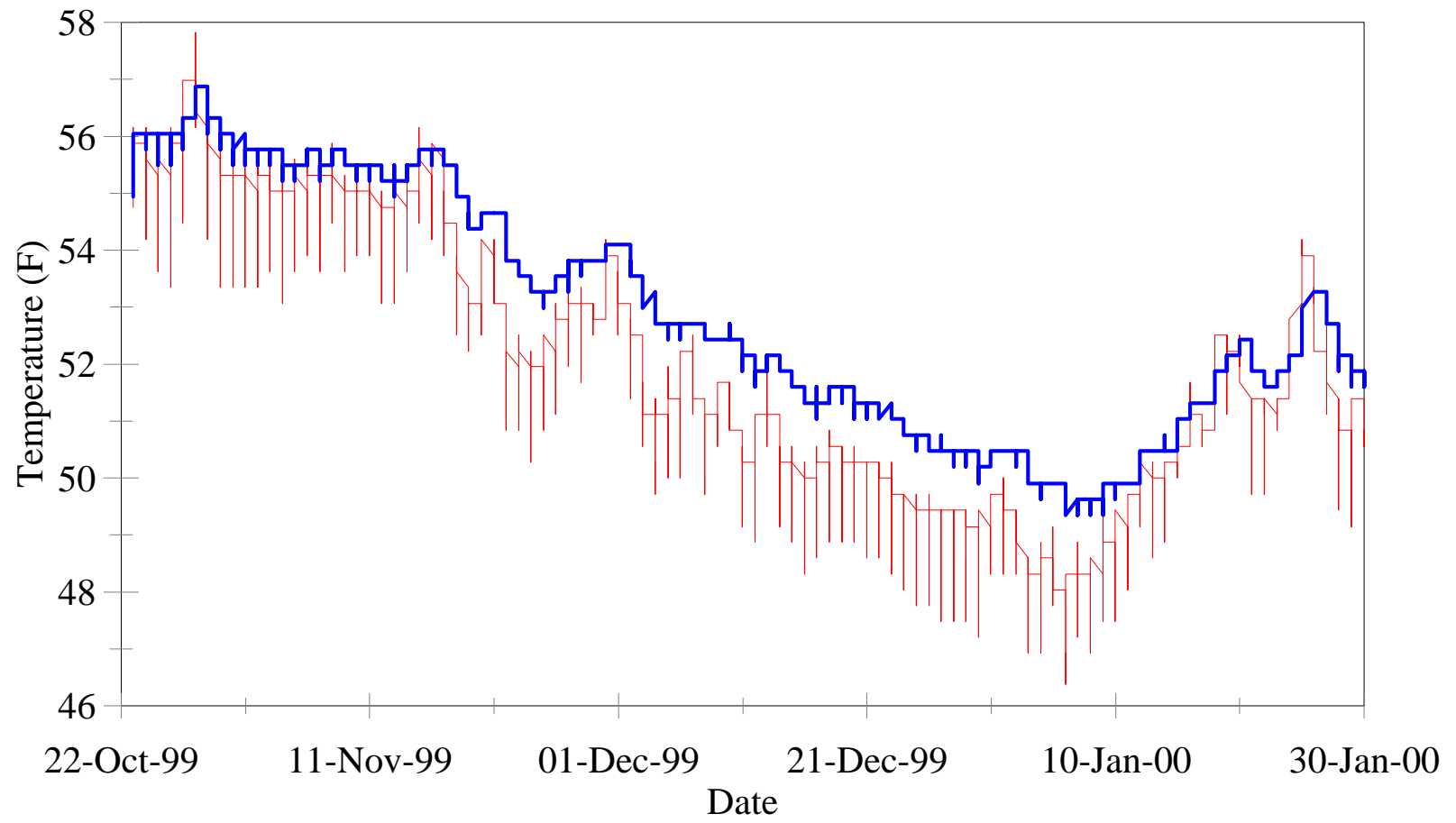
— Surface Temp — Intragravel Temp

R59 P1



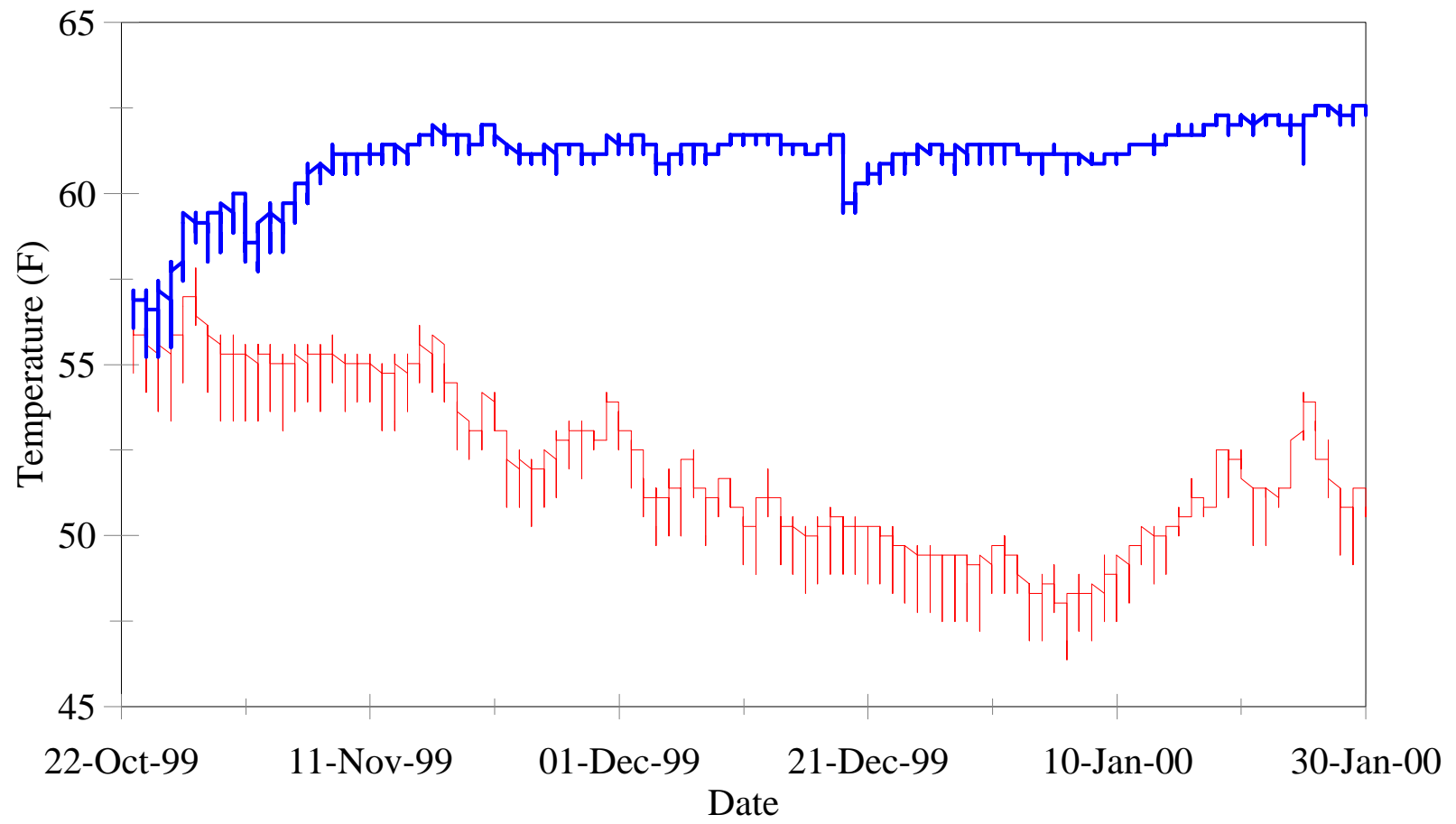
— Surface Temp — Intragravel Temp

R59 P2



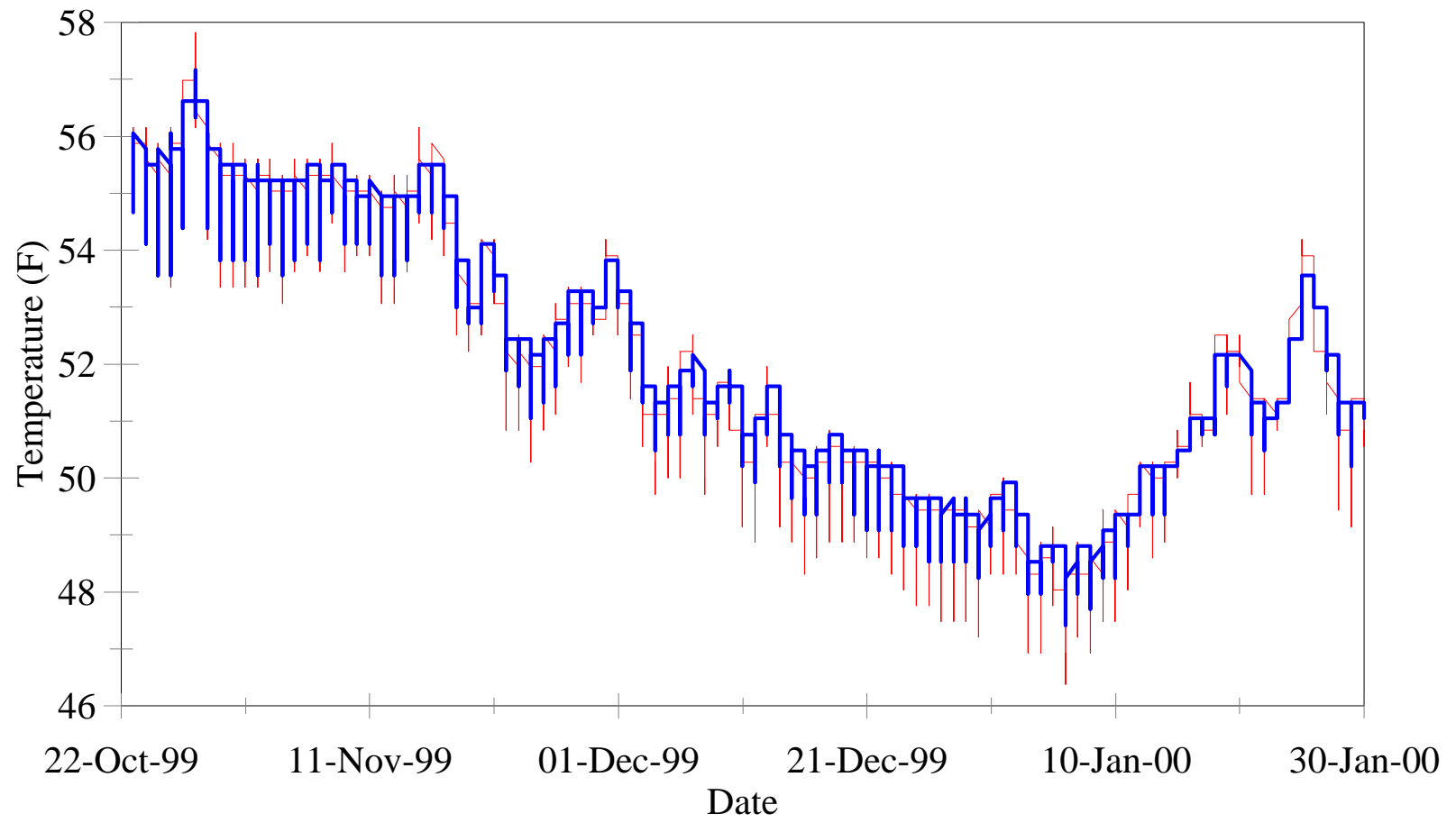
— Surface Temp — Intragravel Temp

R59 P3



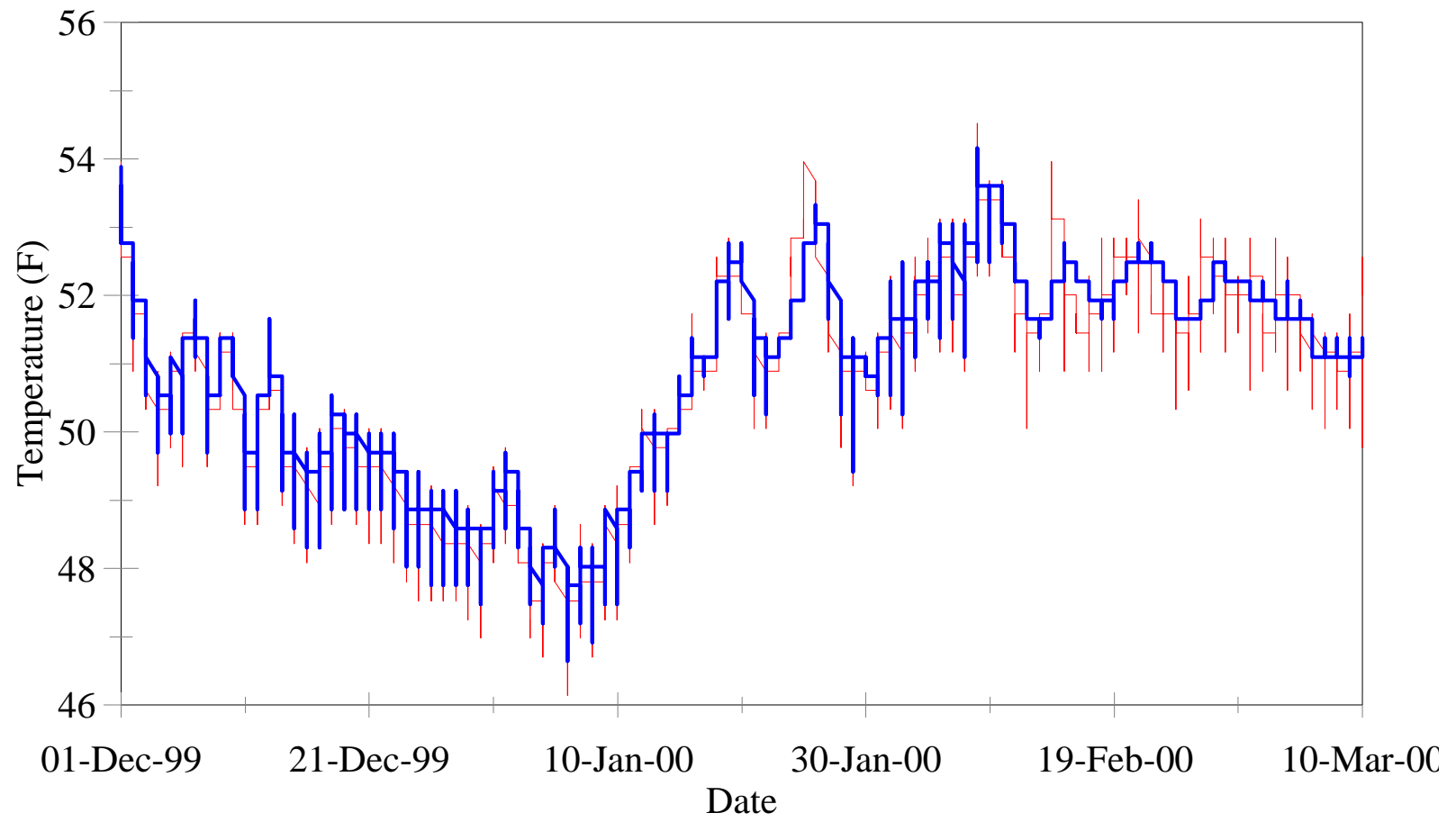
— Surface Temp — Intragravel Temp

R59 P4



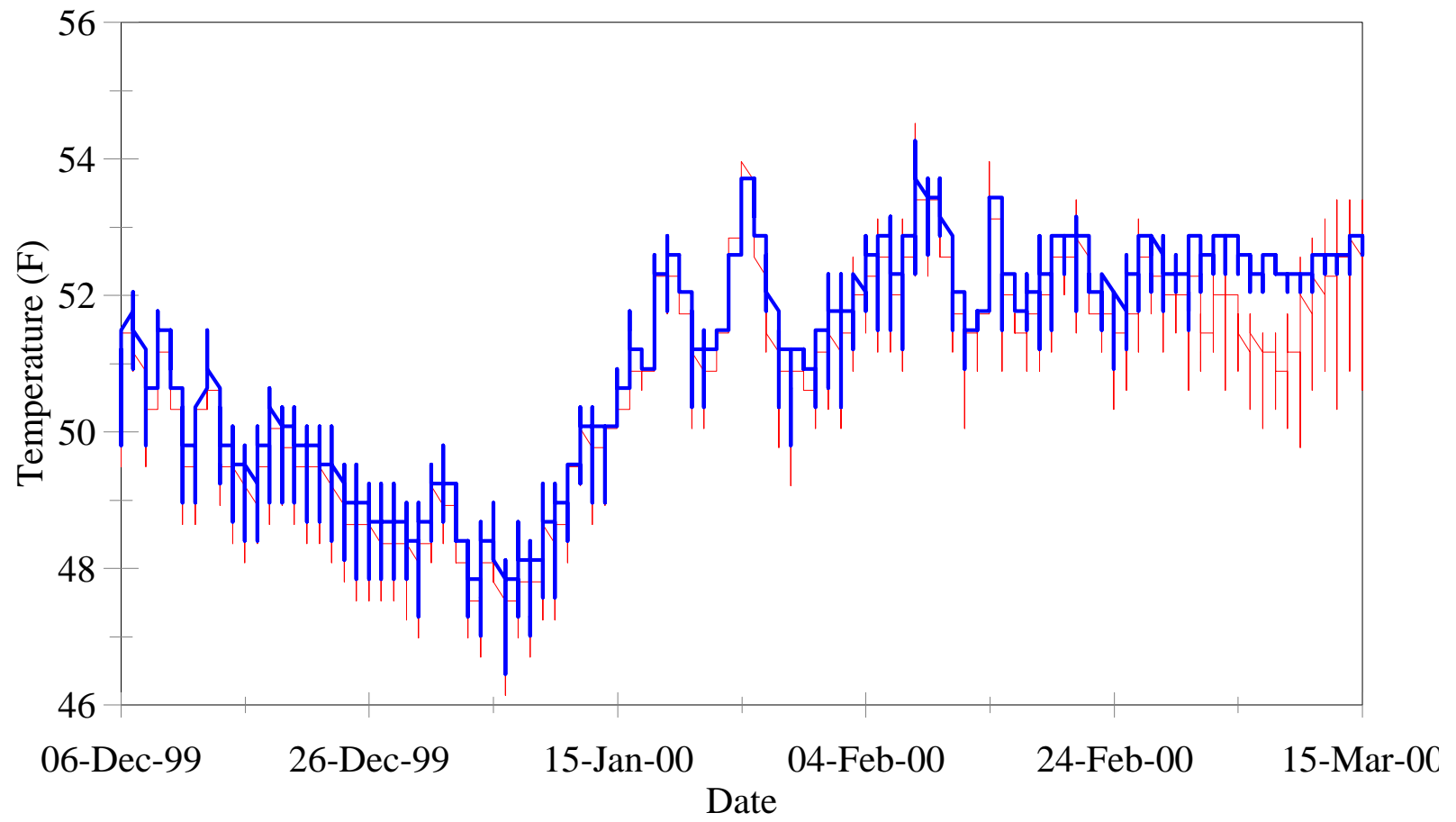
— Surface Temp — Intragravel Temp

R76 P1



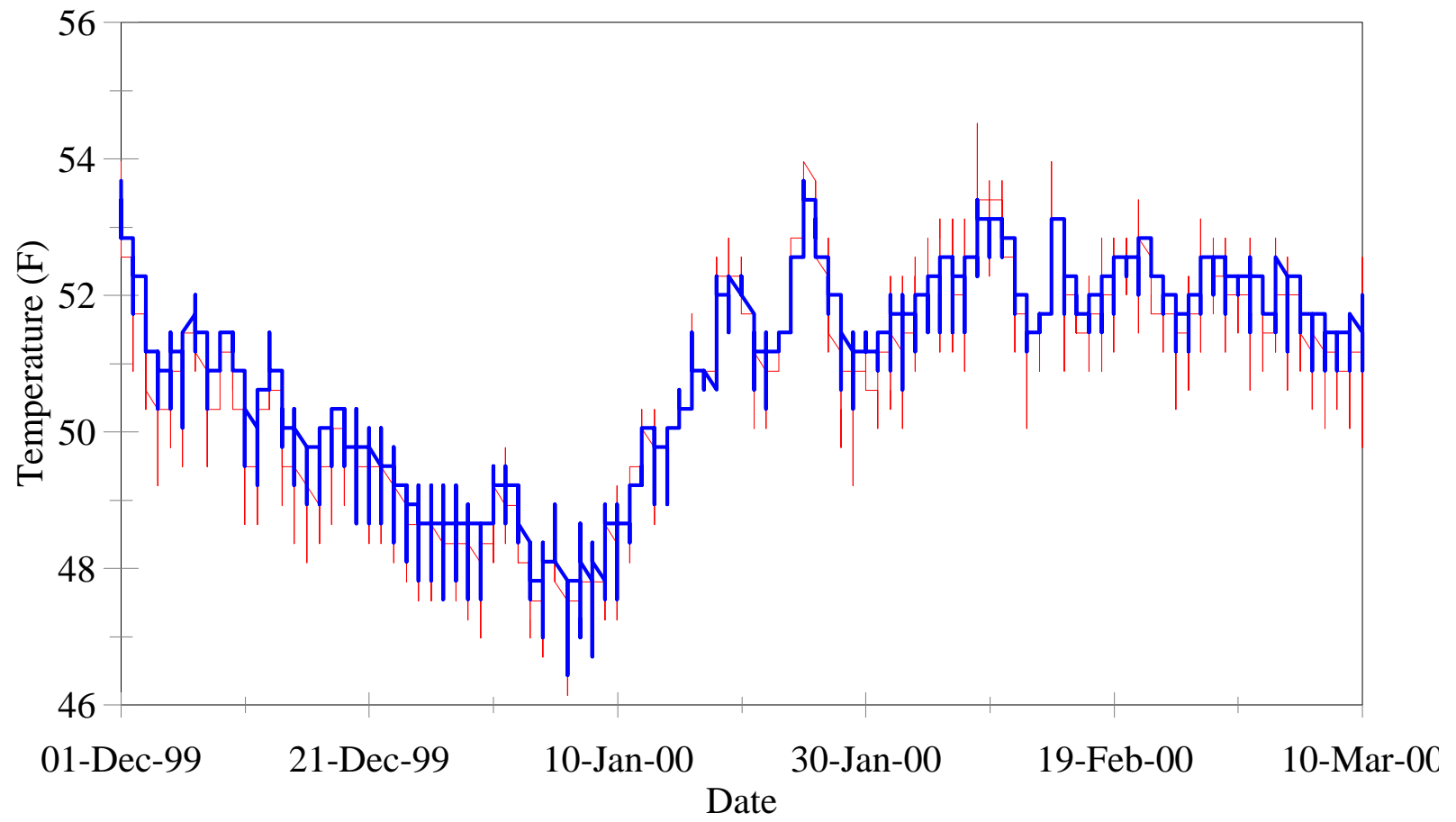
— Surface Temp — Intragravel Temp

R76 P3



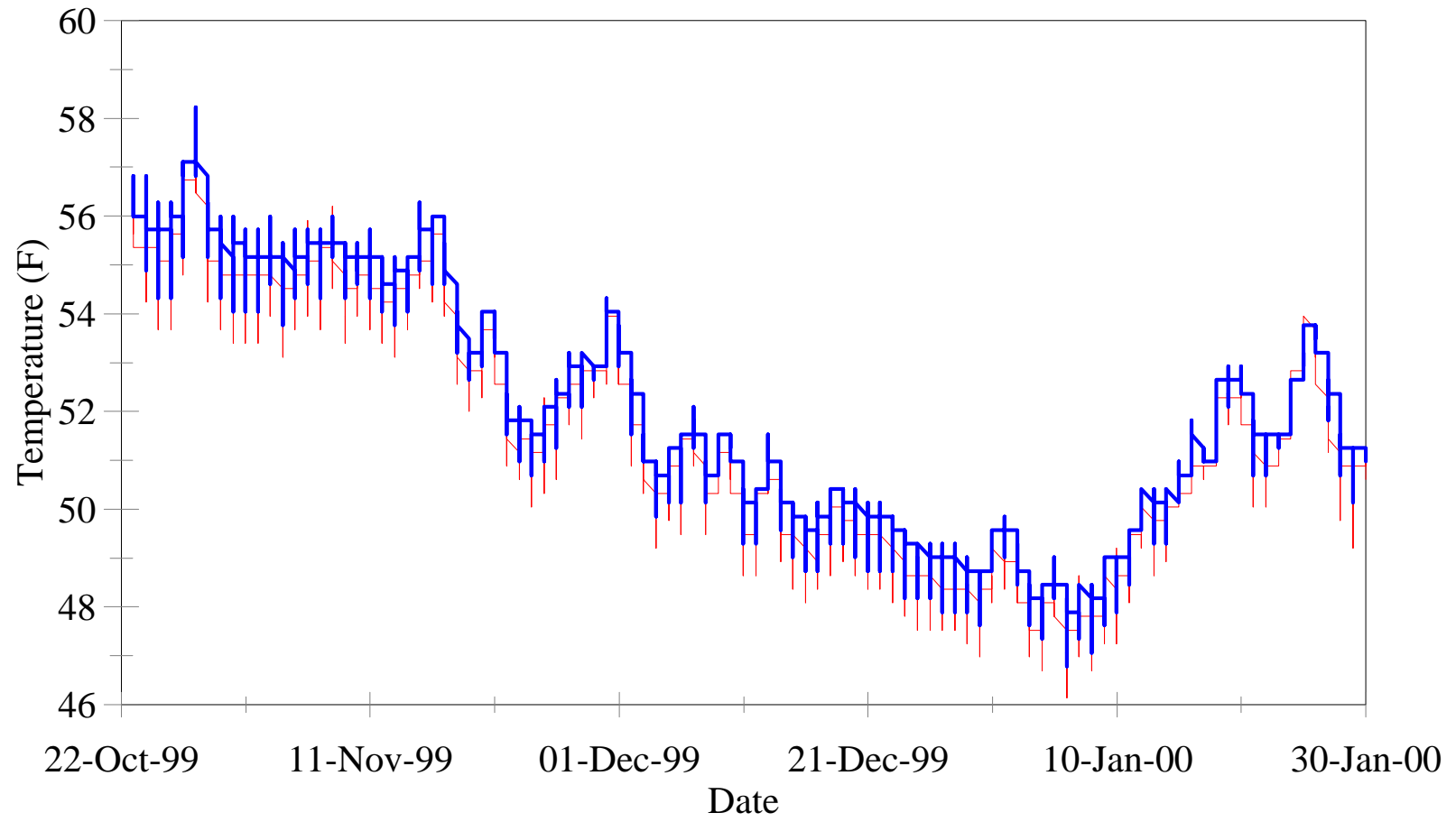
— Surface Temp — Intragravel Temp

R76 P4



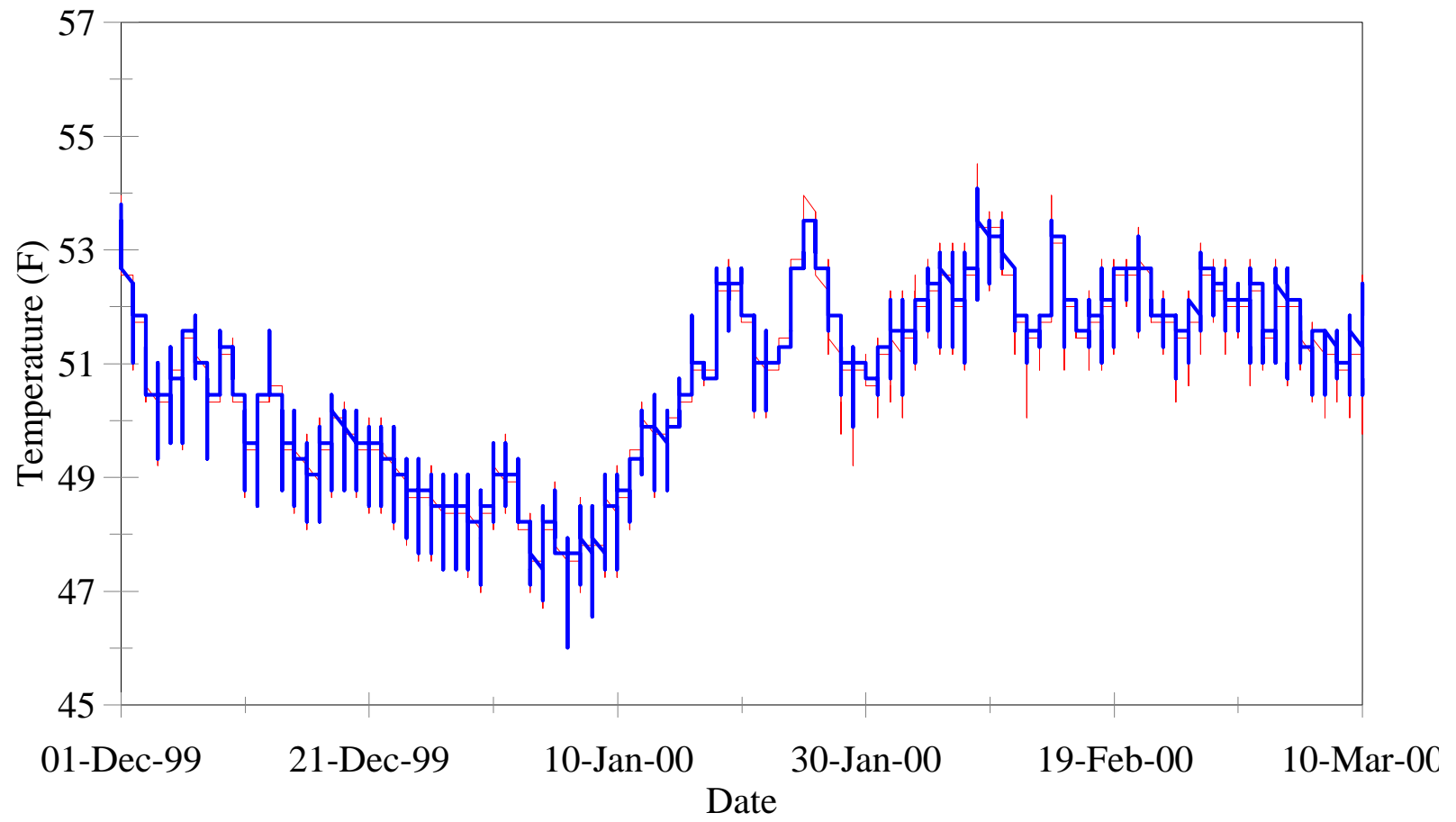
— Surface Temp — Intragravel Temp

R78 P1



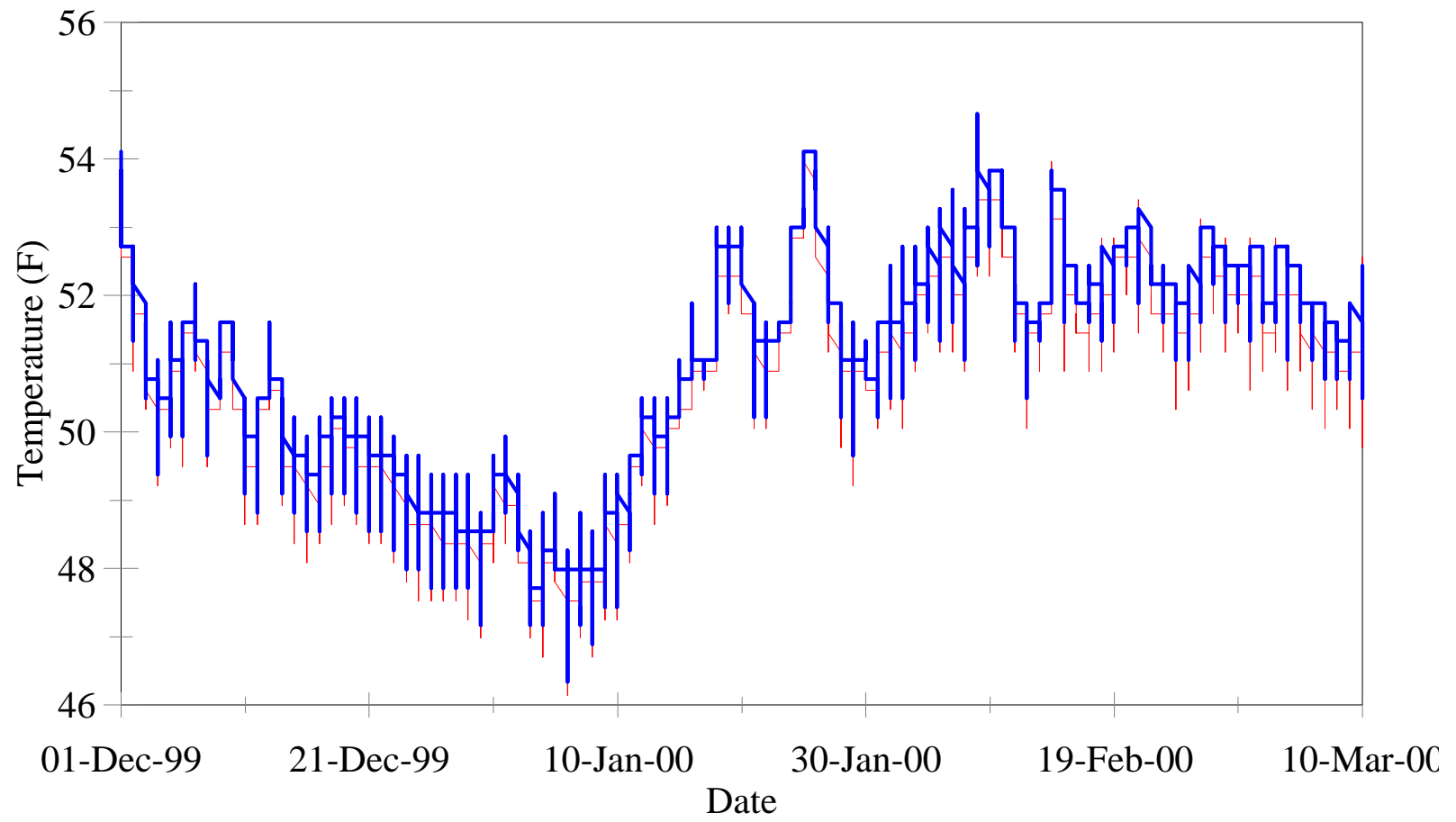
— Surface Temp — Intragravel Temp

R78 P2



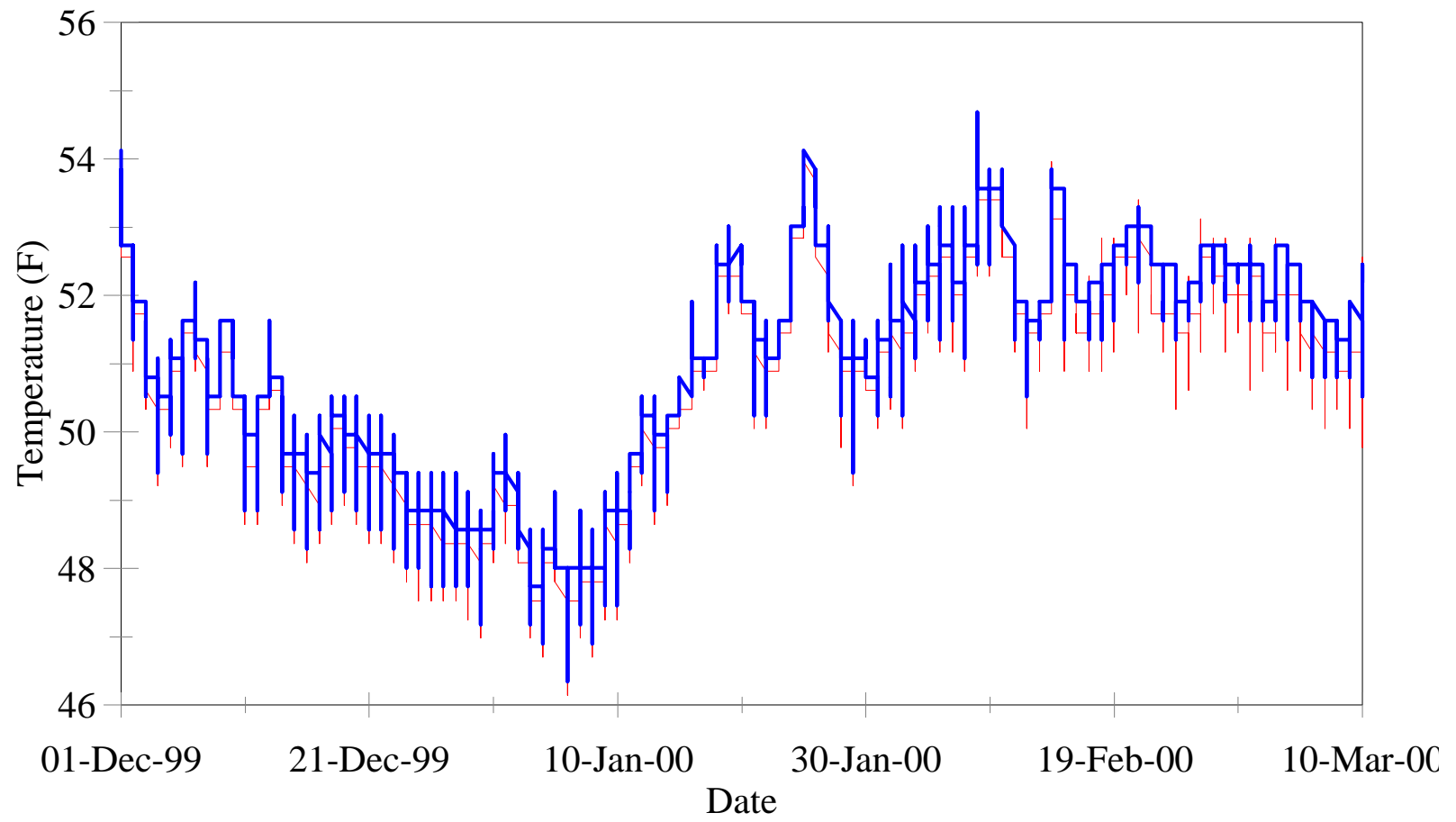
— Surface Temp — Intragravel Temp

R78 P3



— Surface Temp — Intragravel Temp

R78 P4



— Surface Temp — Intragravel Temp

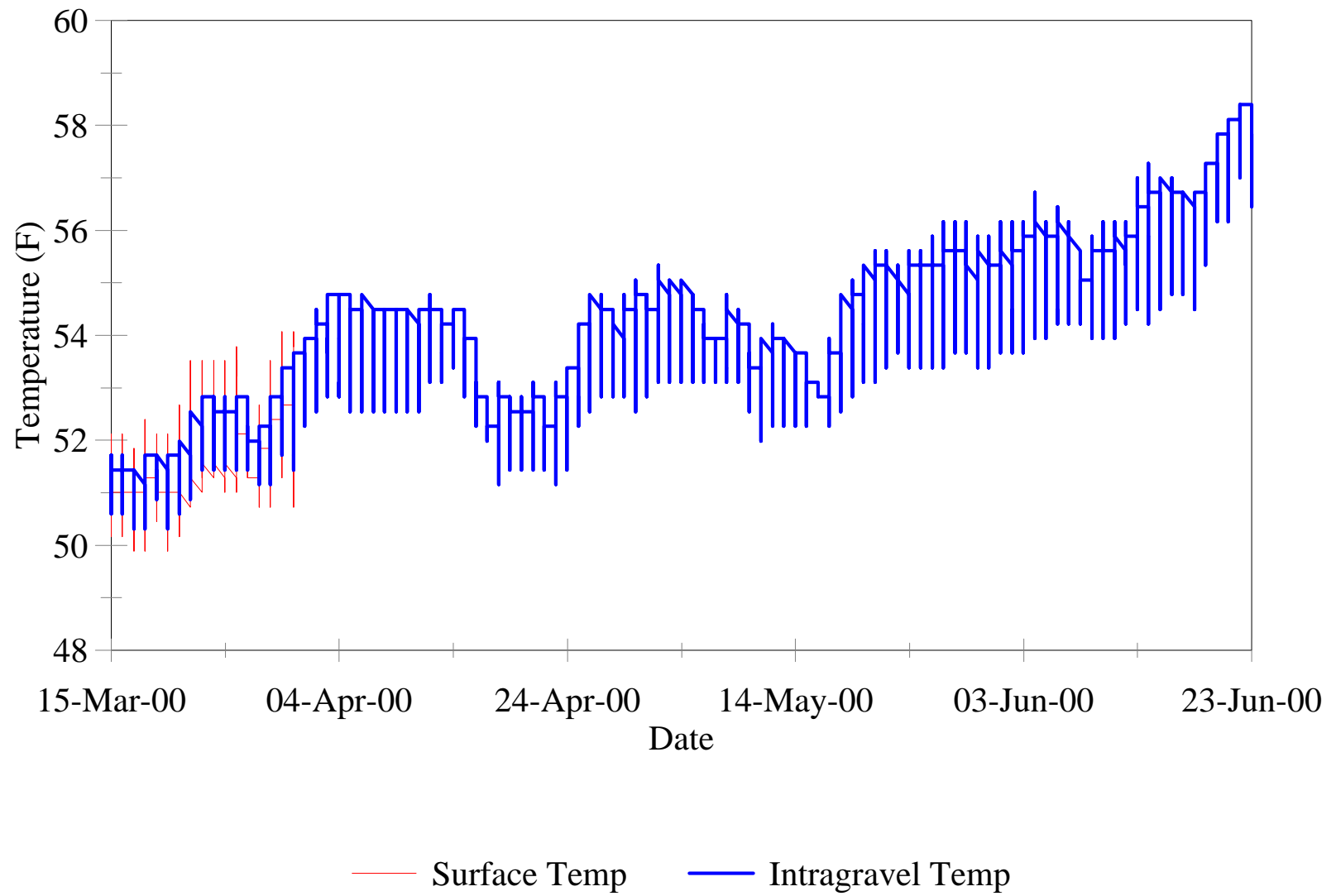
APPENDIX 6

Intragravel and Surface Water Temperatures from March to June 2000.

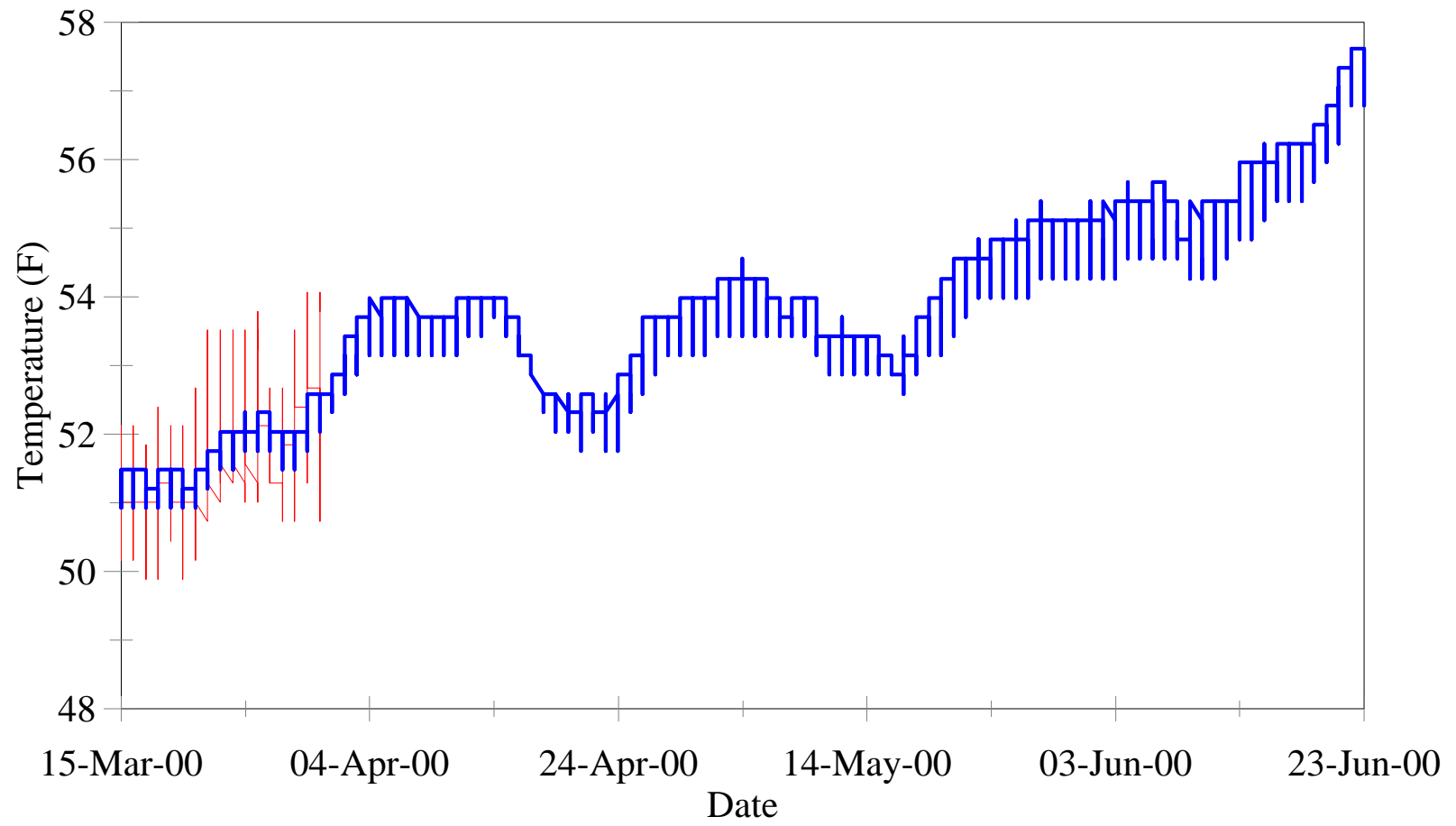
Intragravel water temperatures were measured at 30-minute intervals with *Onset Tidbit* thermographs buried with piezometers in artificial redds at 25 study riffles in the Stanislaus river between Goodwin Dam and Oakdale. Thermographs also monitored surface flows near the river margin near riffles DFG2, TMA, R5, R10, R14, R19, R28A, R43, R59, and R76. Comparisons between surface and intragravel measurements at riffles where no surface thermograph was installed utilized the surface data collected at the closest riffle.

Forty-three buried thermographs at Lovers Leap (riffles R13-R20), Valley Oak Recreational Part (riffles R57-R59), and Oakdale Recreational Park (riffles R76 and R78) recorded data through June 2000. The magnitude and fluctuation in intragravel water temperatures were nearly identical to those of the surface flow at 19 piezometers, which include R13 P2-P4, R14 P2, R15 P1-P4, R16 P1, R16 P2, R16 P4, R19 P3, R20 P1-P4, R57 P1, R57 P2, and R57 P4. As examples of these sites, thermograph data are presented in this appendix for piezometers R15 P1 and R57 P1. The data from the 21 buried thermographs that began to deviate in either magnitude or fluctuation from the surface temperatures after intensive rain storms began in late January 2000 or after flood control releases began in mid-February 2000 are also presented in this appendix. Flood control releases occurred from 14 February until 21 June 2000, when flows returned to 300 cfs.

R14 P1

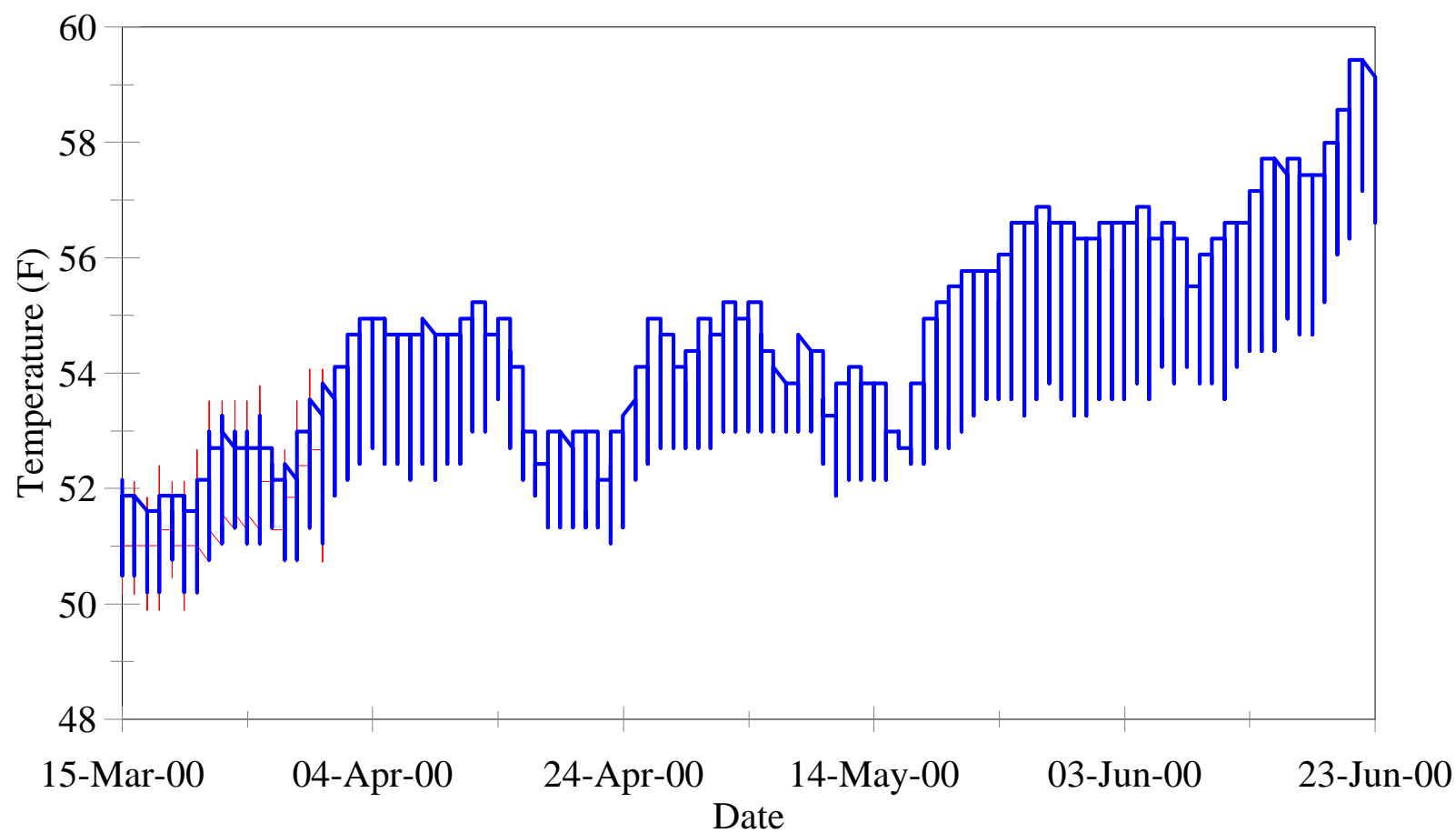


R14 P3



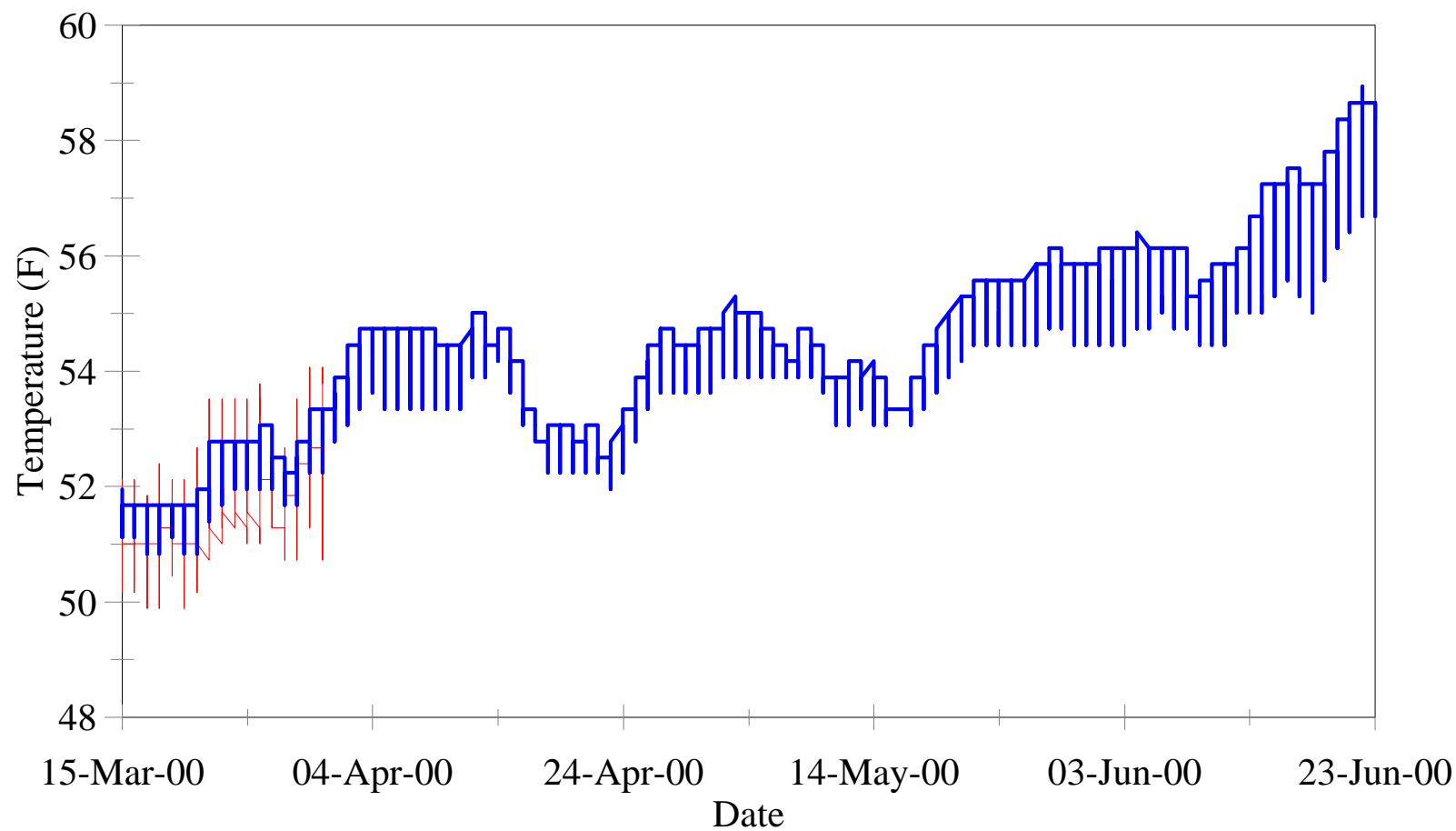
— Surface Temp — Intragravel Temp

R14A P1



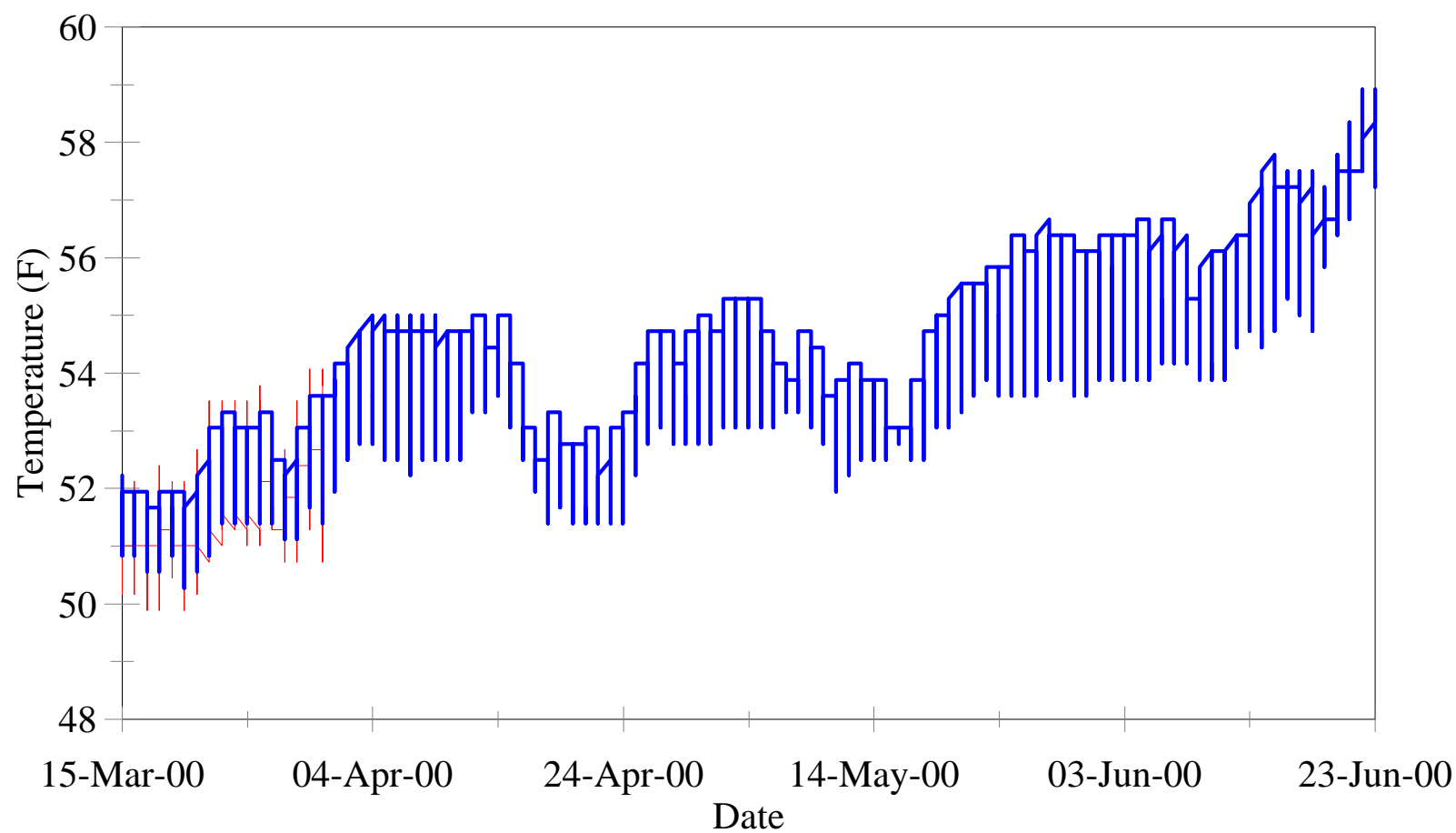
— Surface Temp — Intragravel Temp

R14A P2



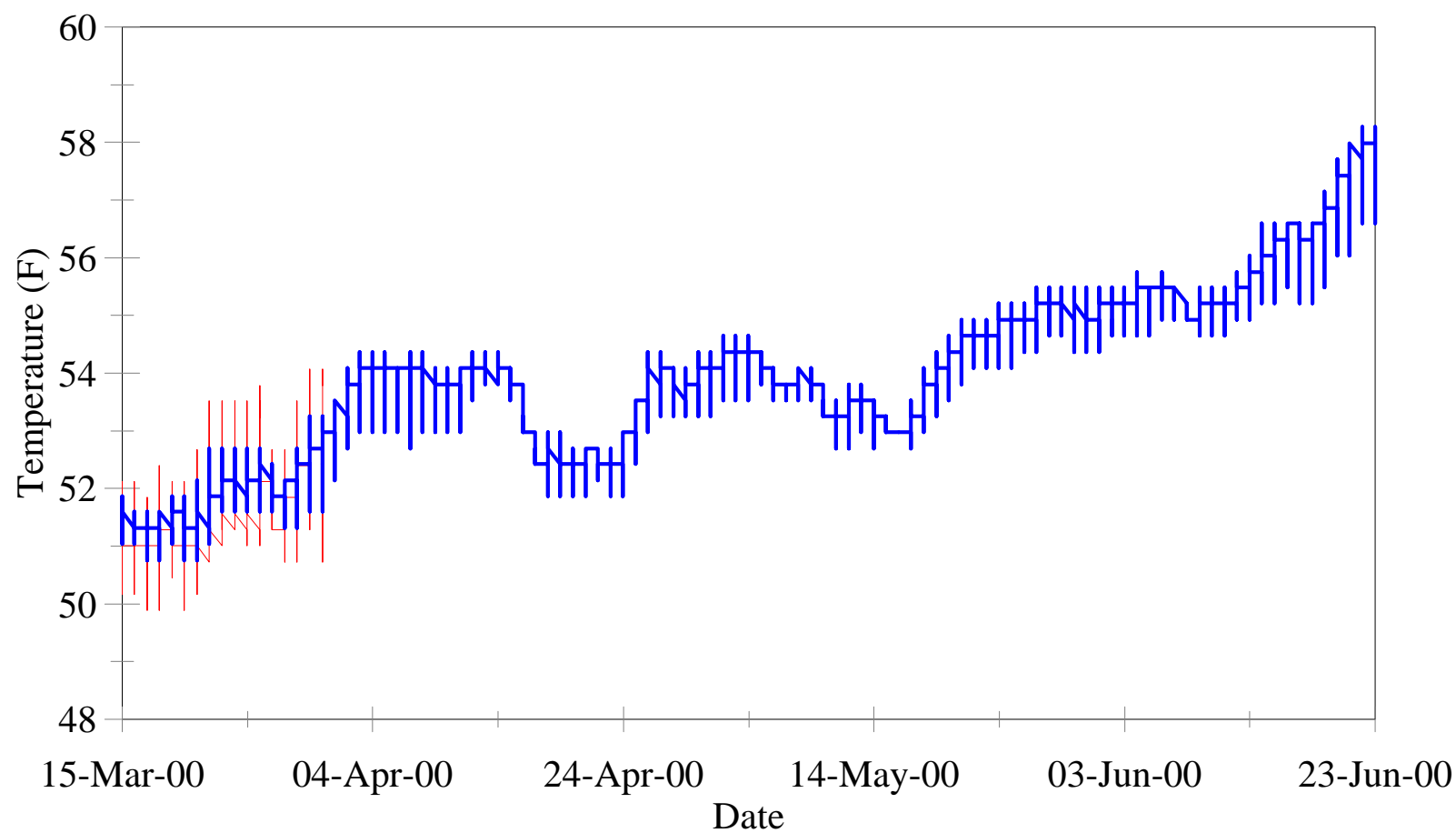
— Surface Temp — Intragravel Temp

R14A P3



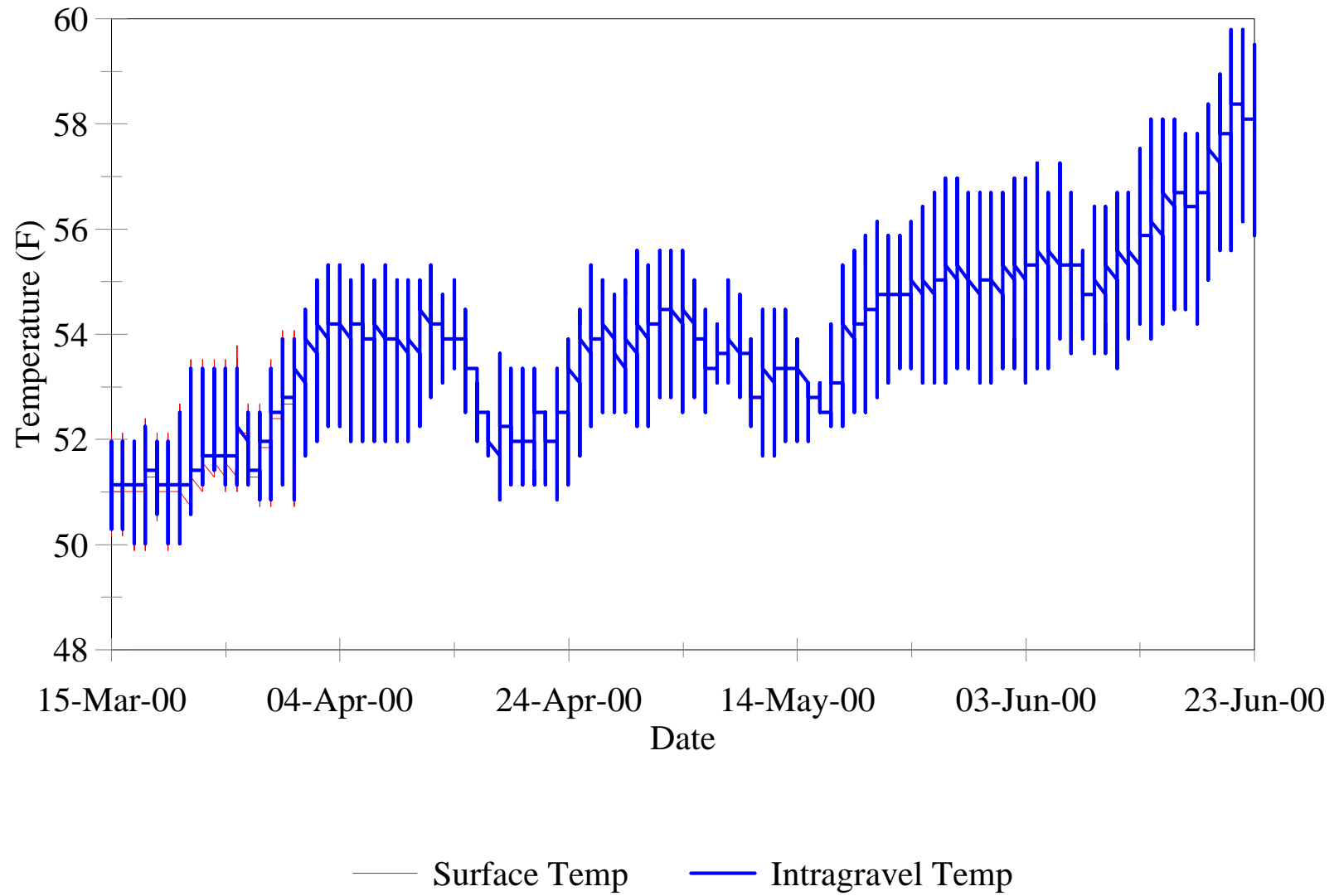
— Surface Temp — Intragravel Temp

R14A P4

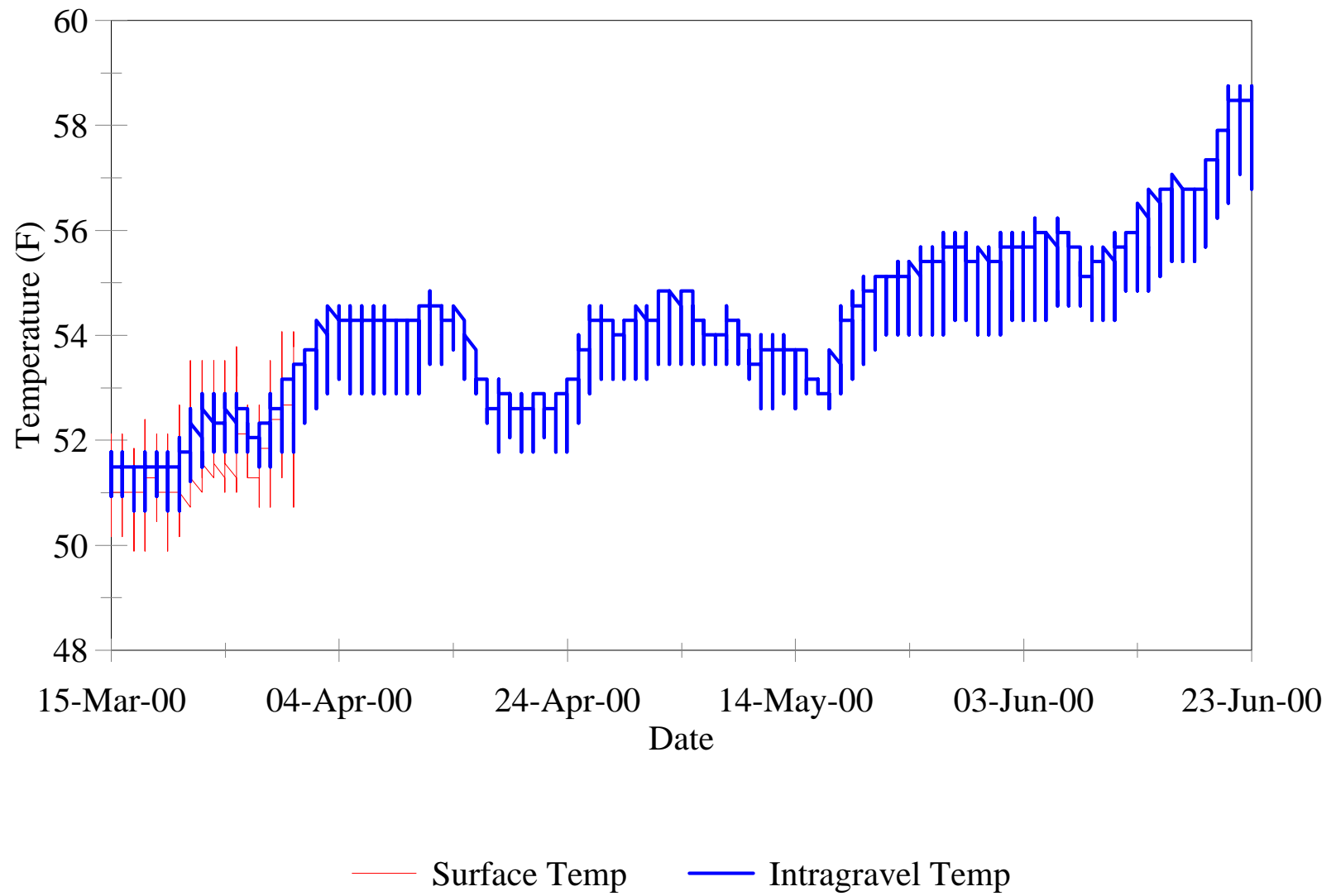


— Surface Temp — Intragravel Temp

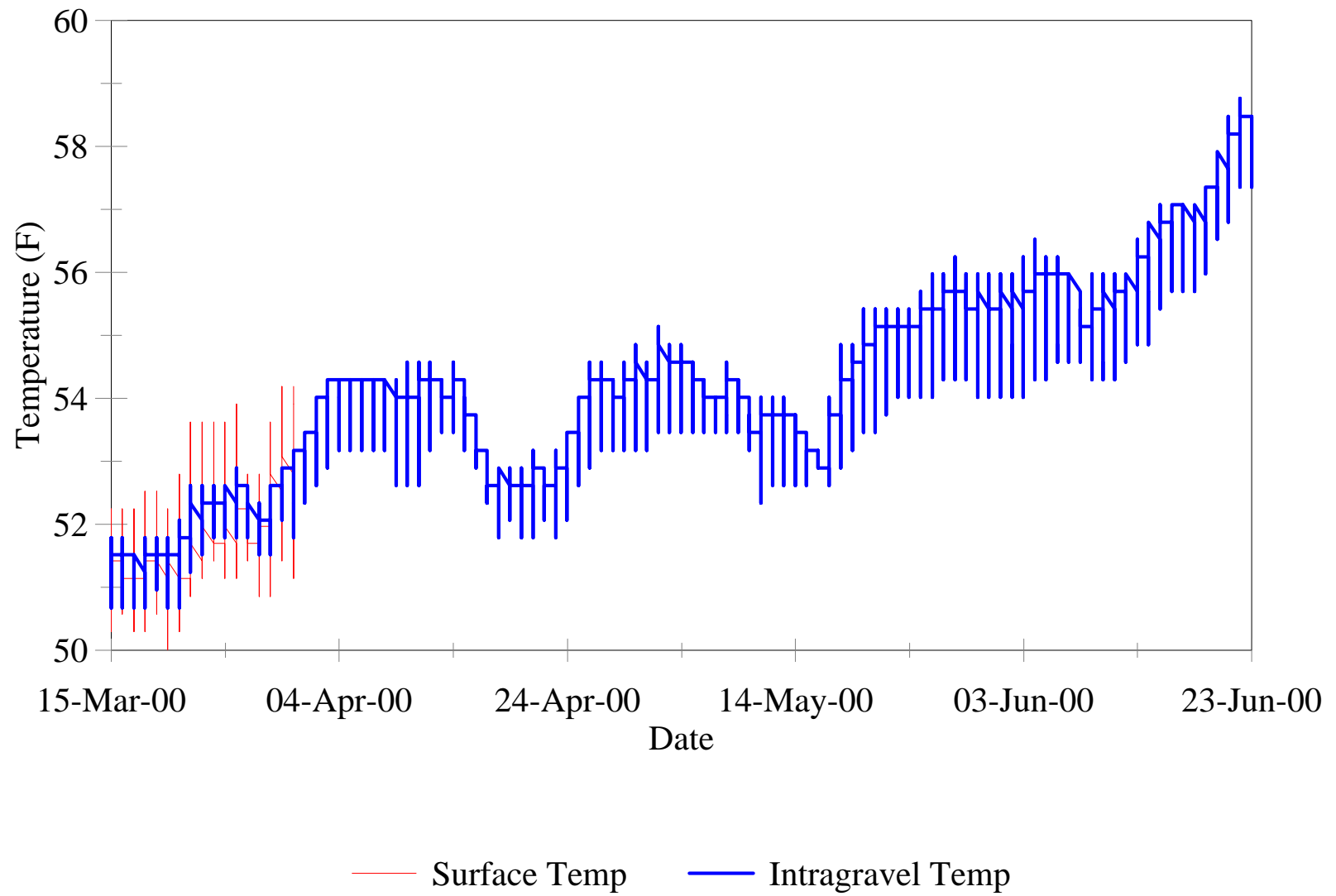
R15 P1



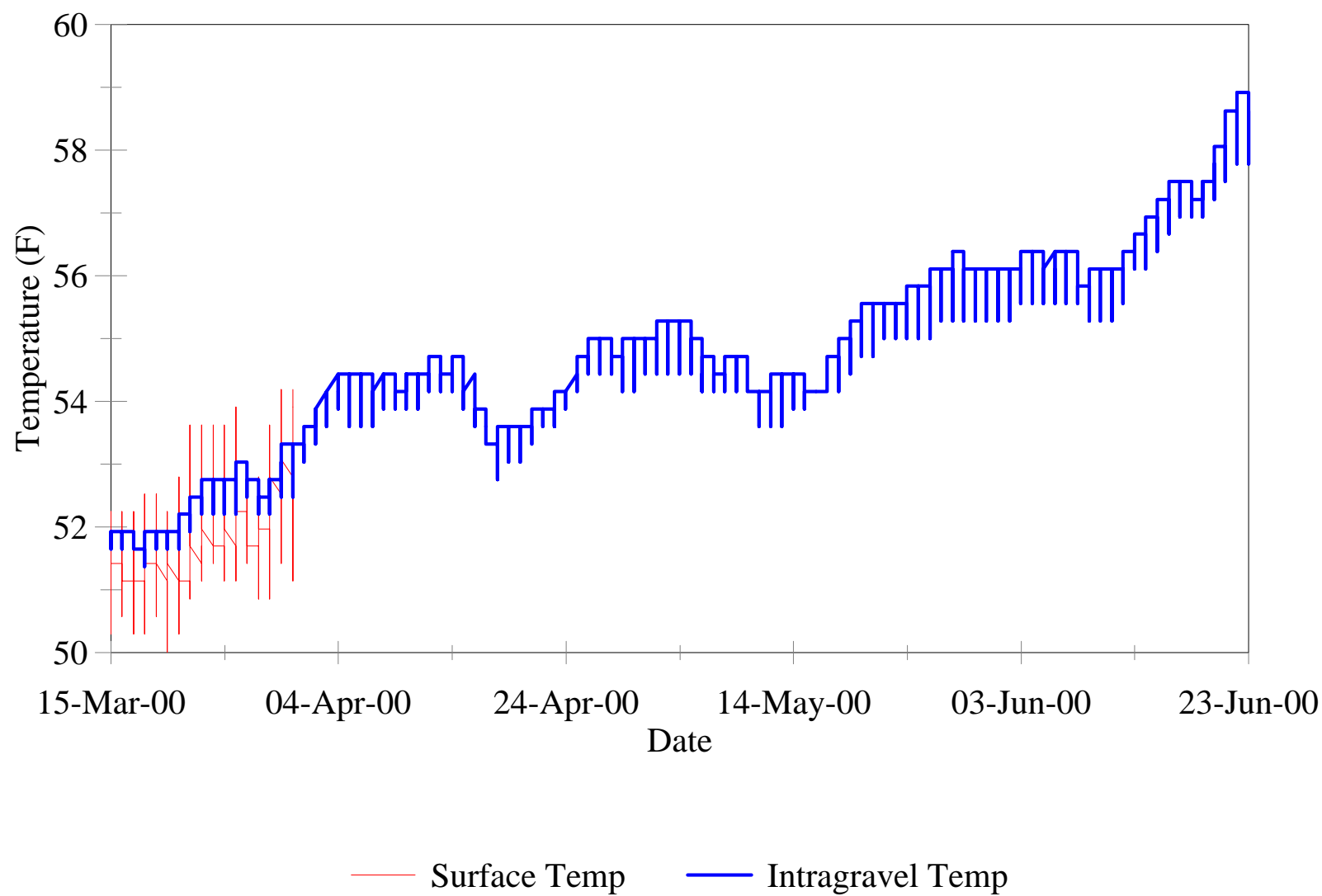
R16 P3



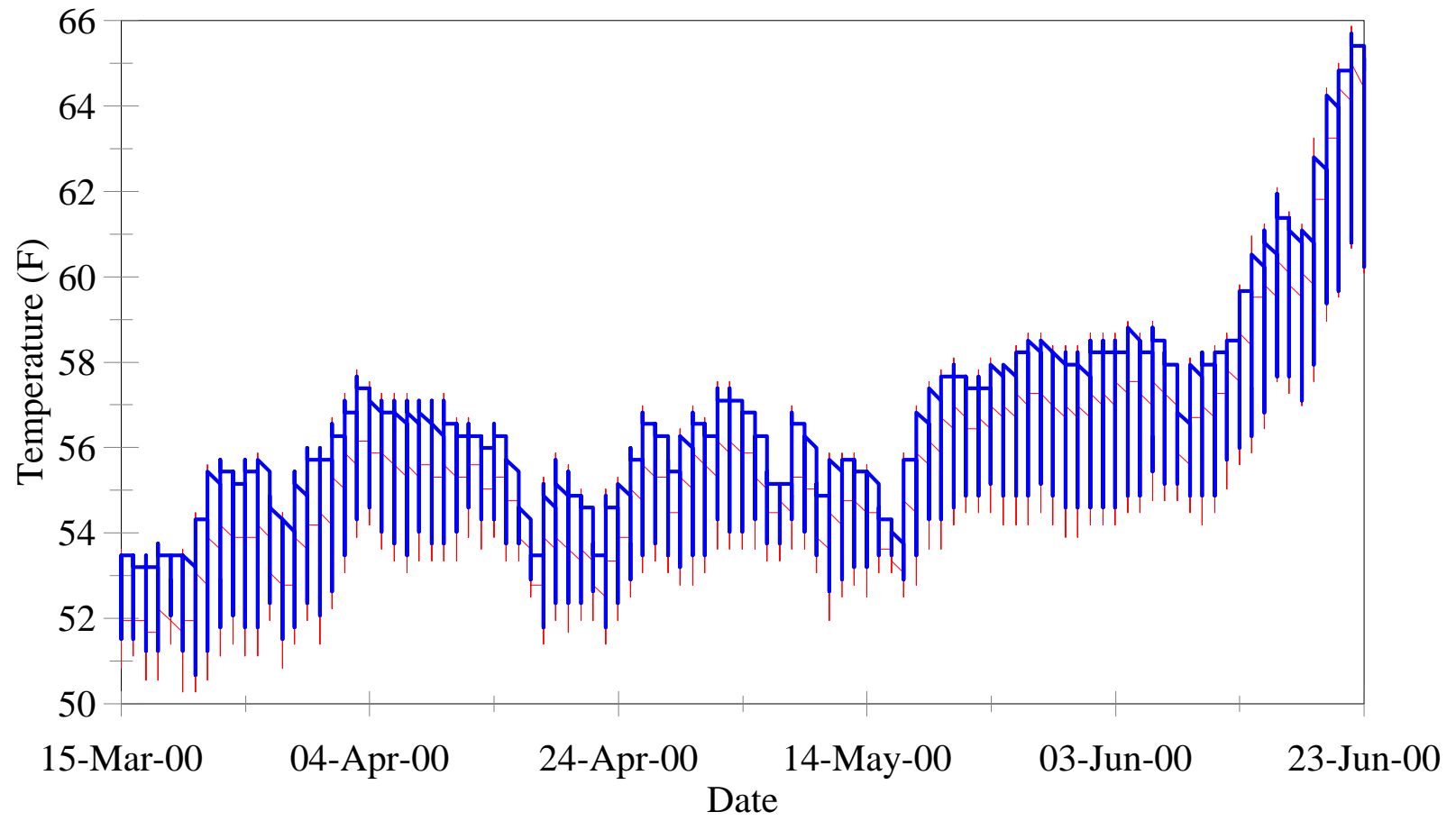
R19 P1



R19 P2

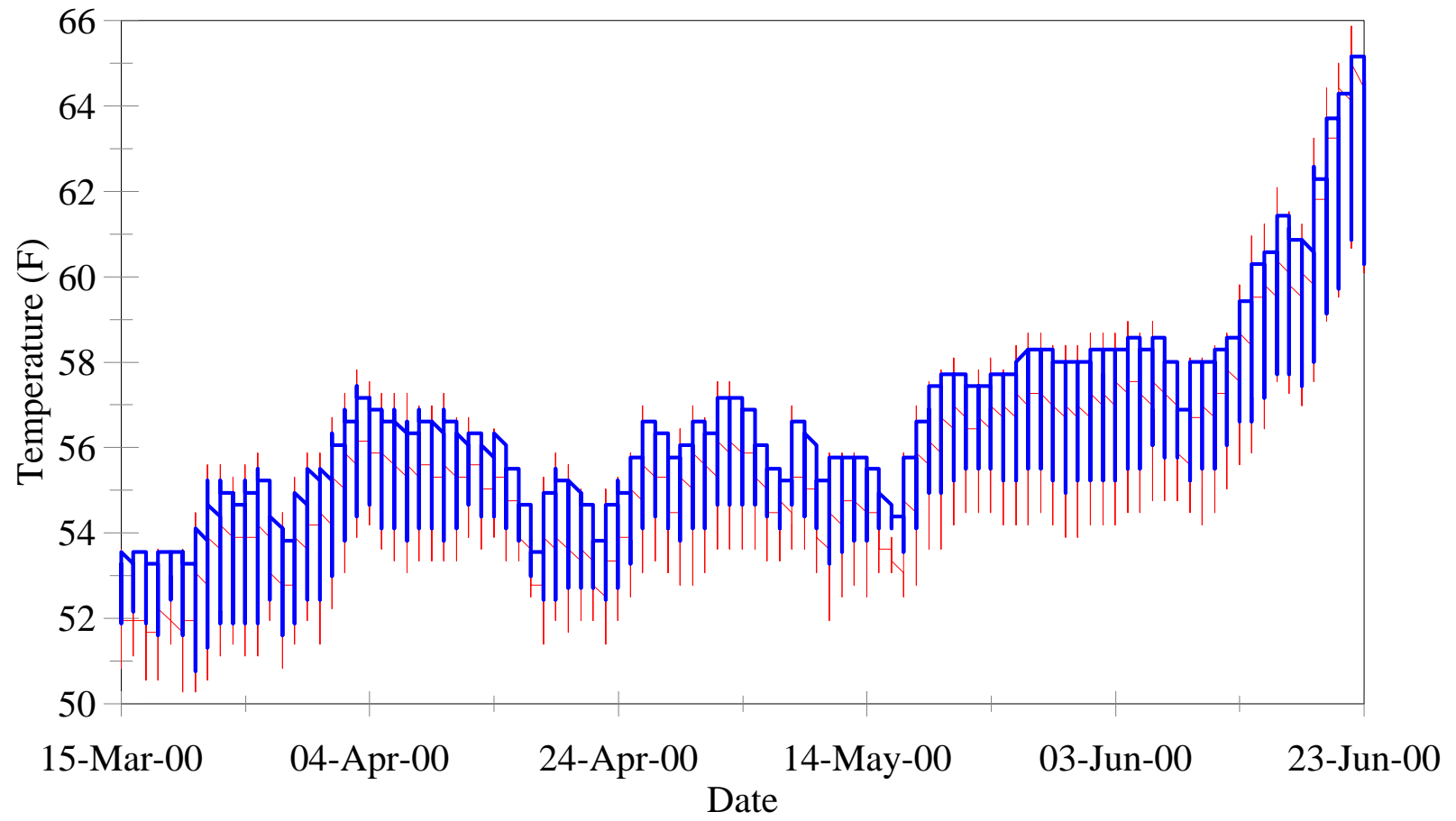


R57 P1



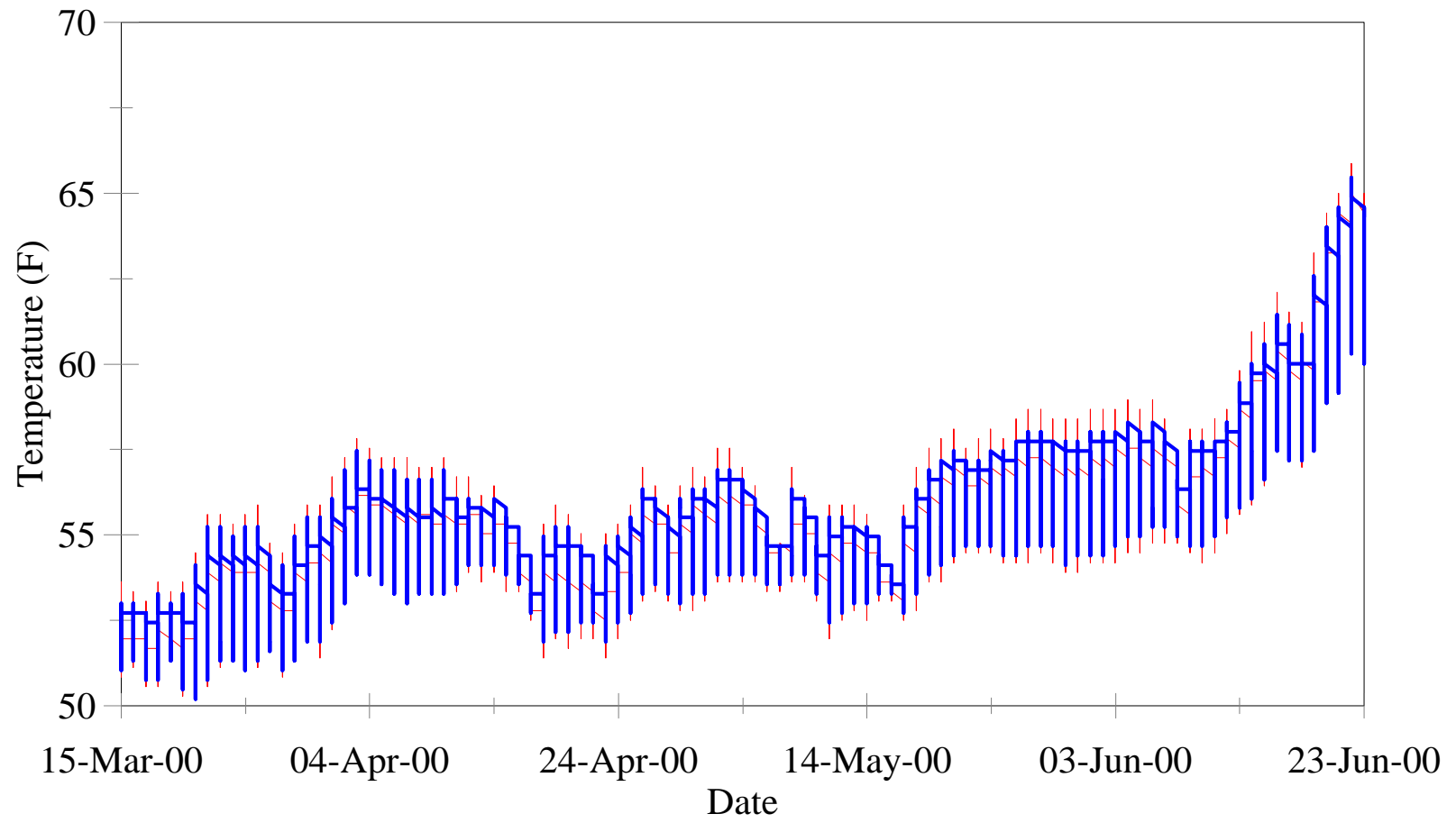
— Surface Temp — Intragravel Temp

R57 P3



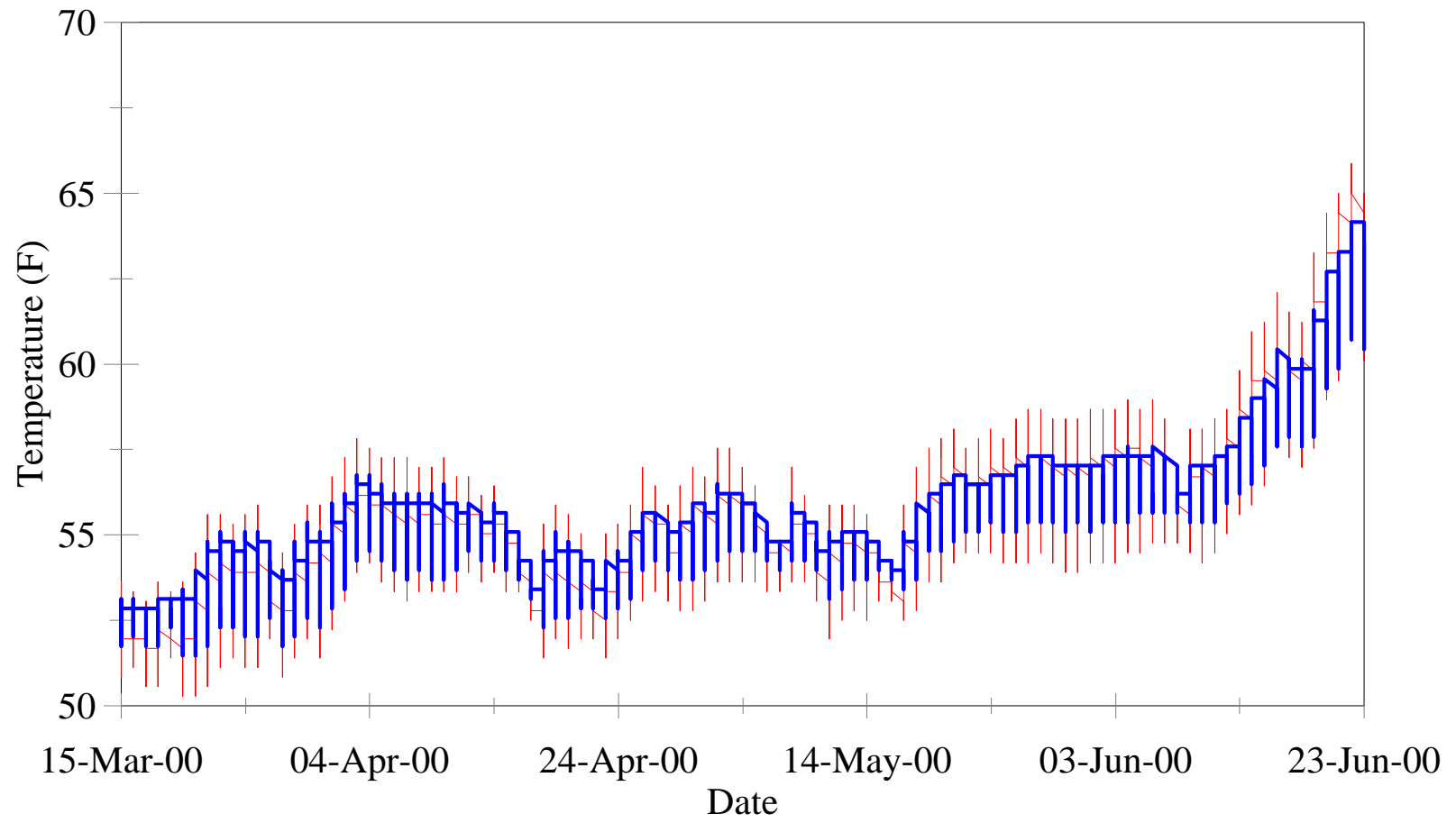
— Surface Temp — Intragravel Temp

R58 P1



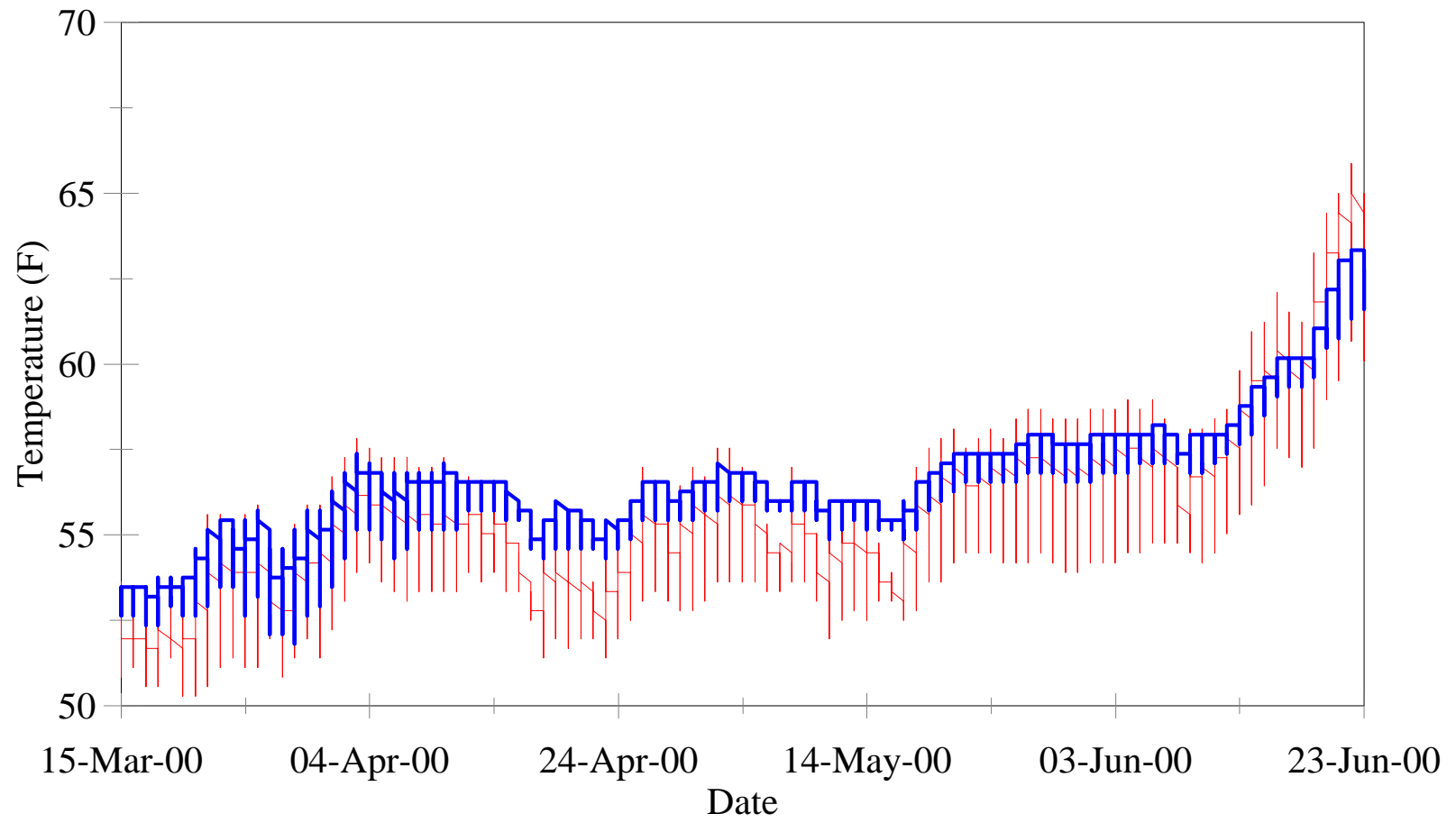
— Surface Temp — Intragravel Temp

R58 P2



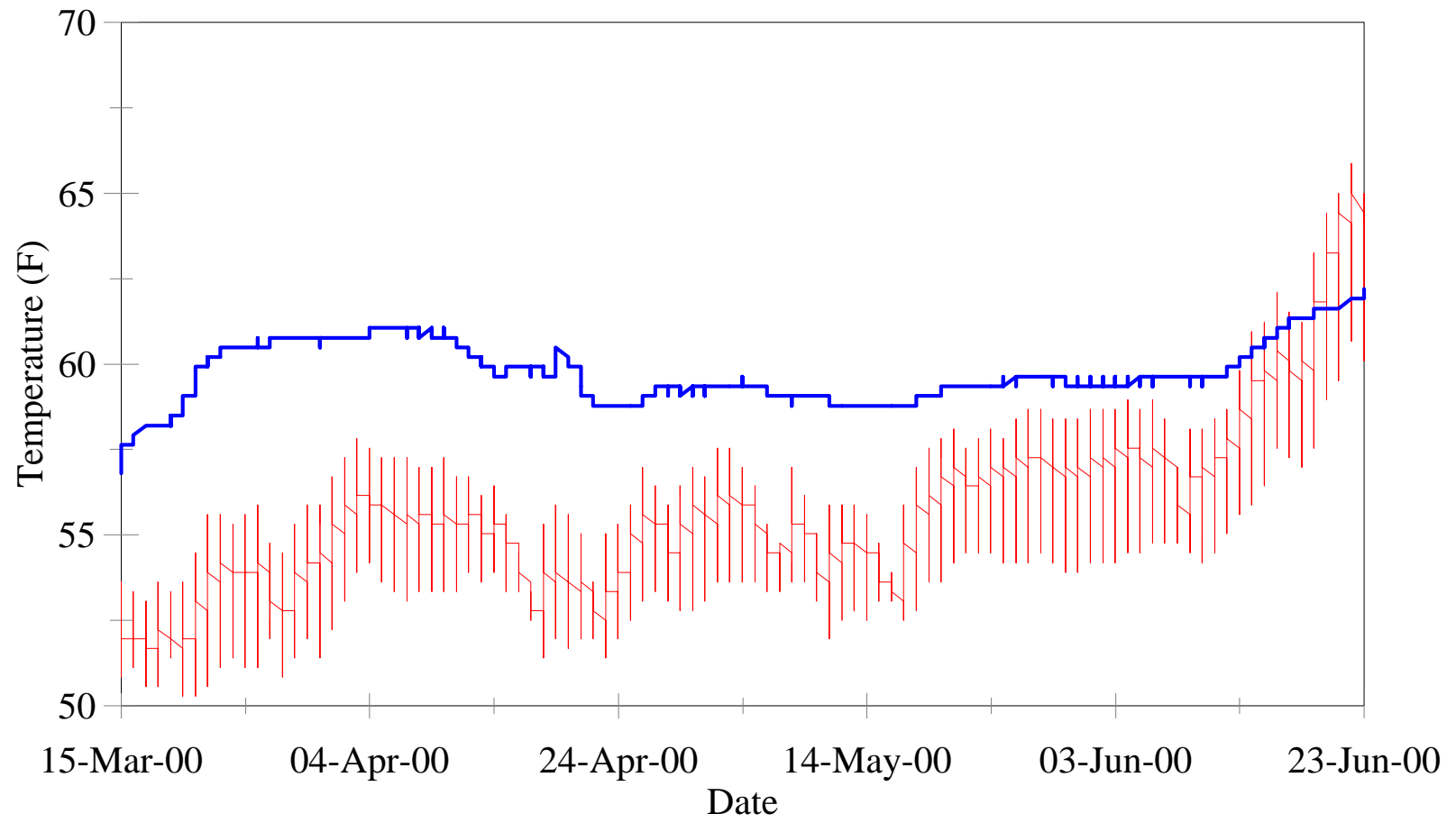
— Surface Temp — Intragravel Temp

R58 P3



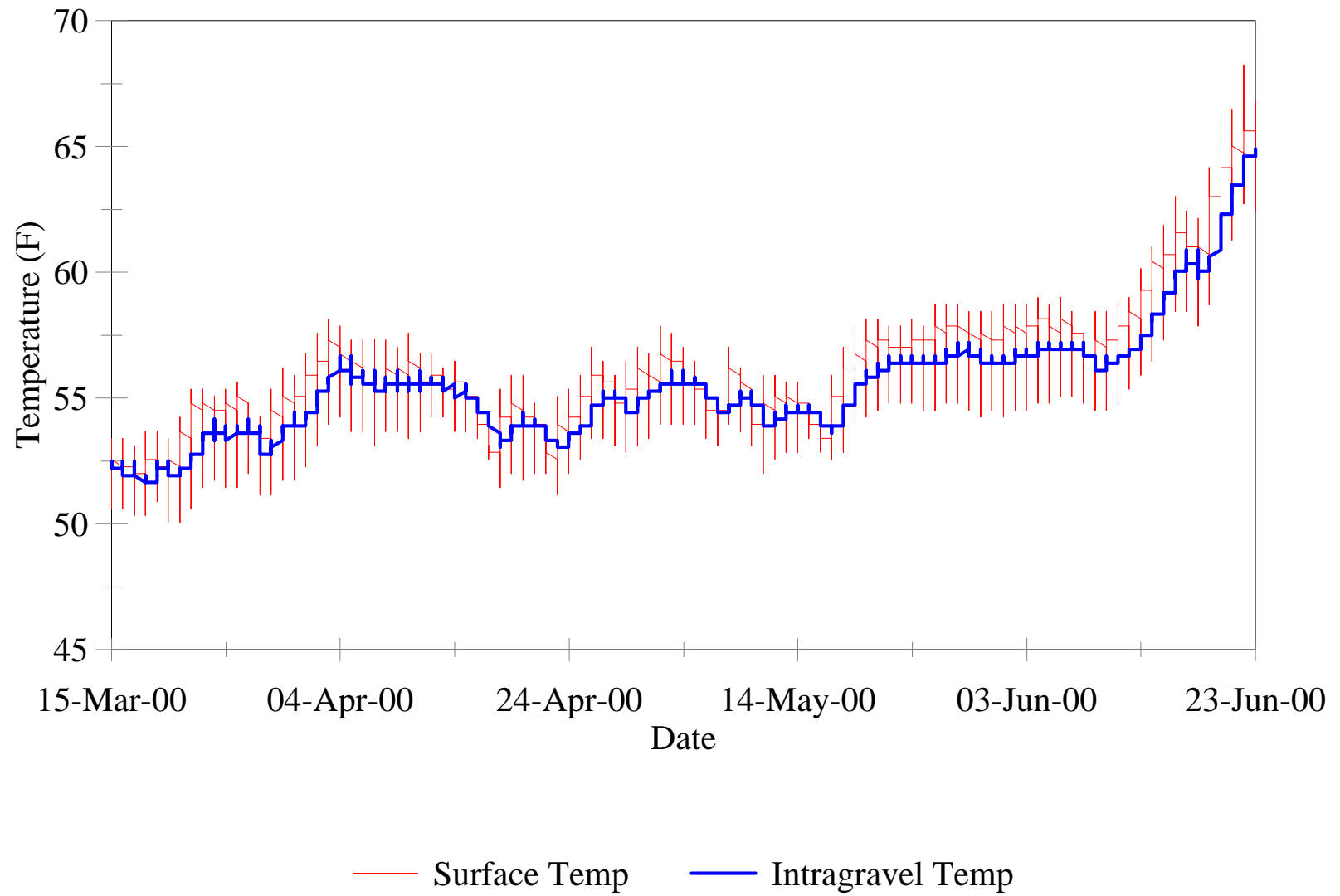
— Surface Temp — Intragravel Temp

R58 P4

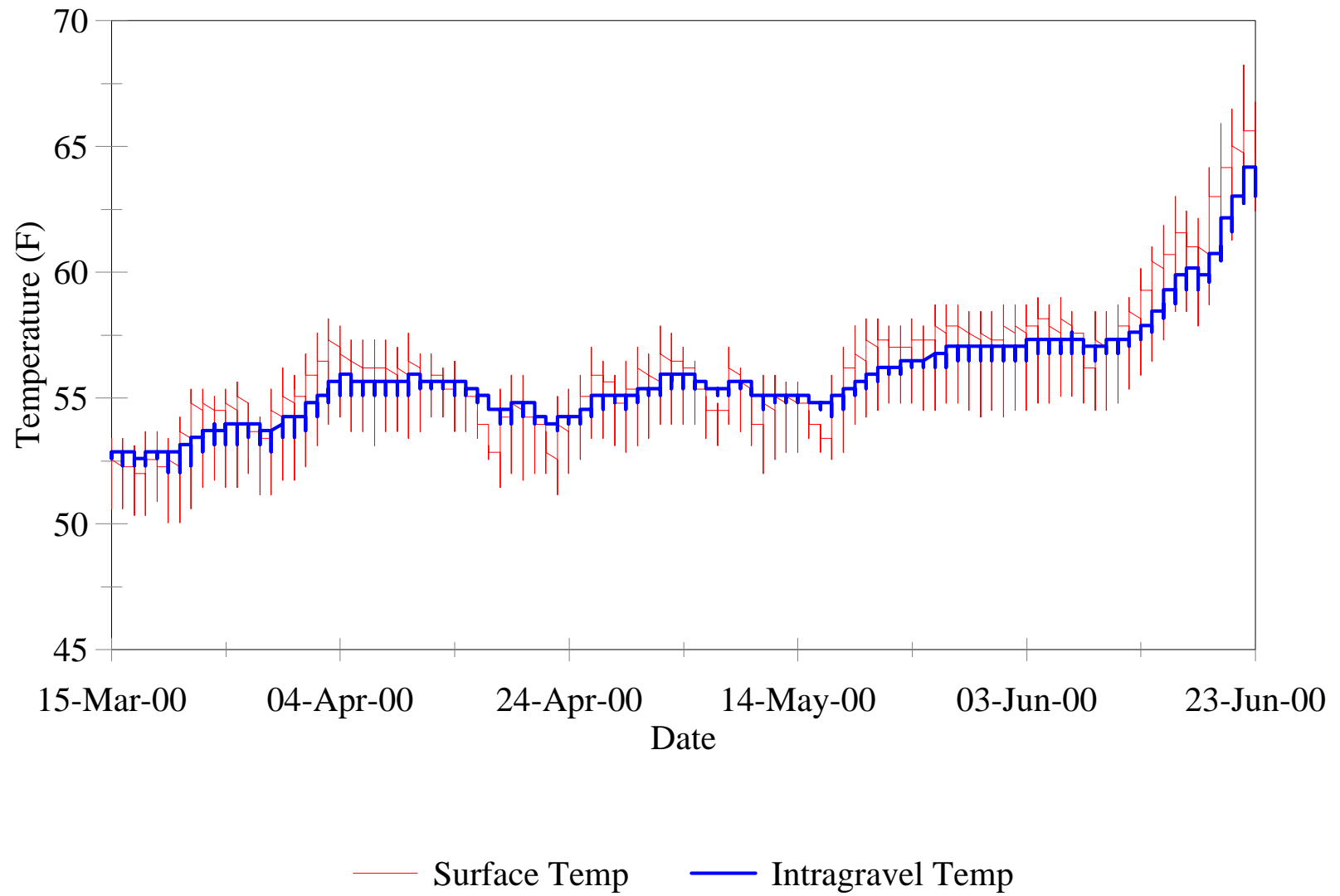


— Surface Temp — Intragravel Temp

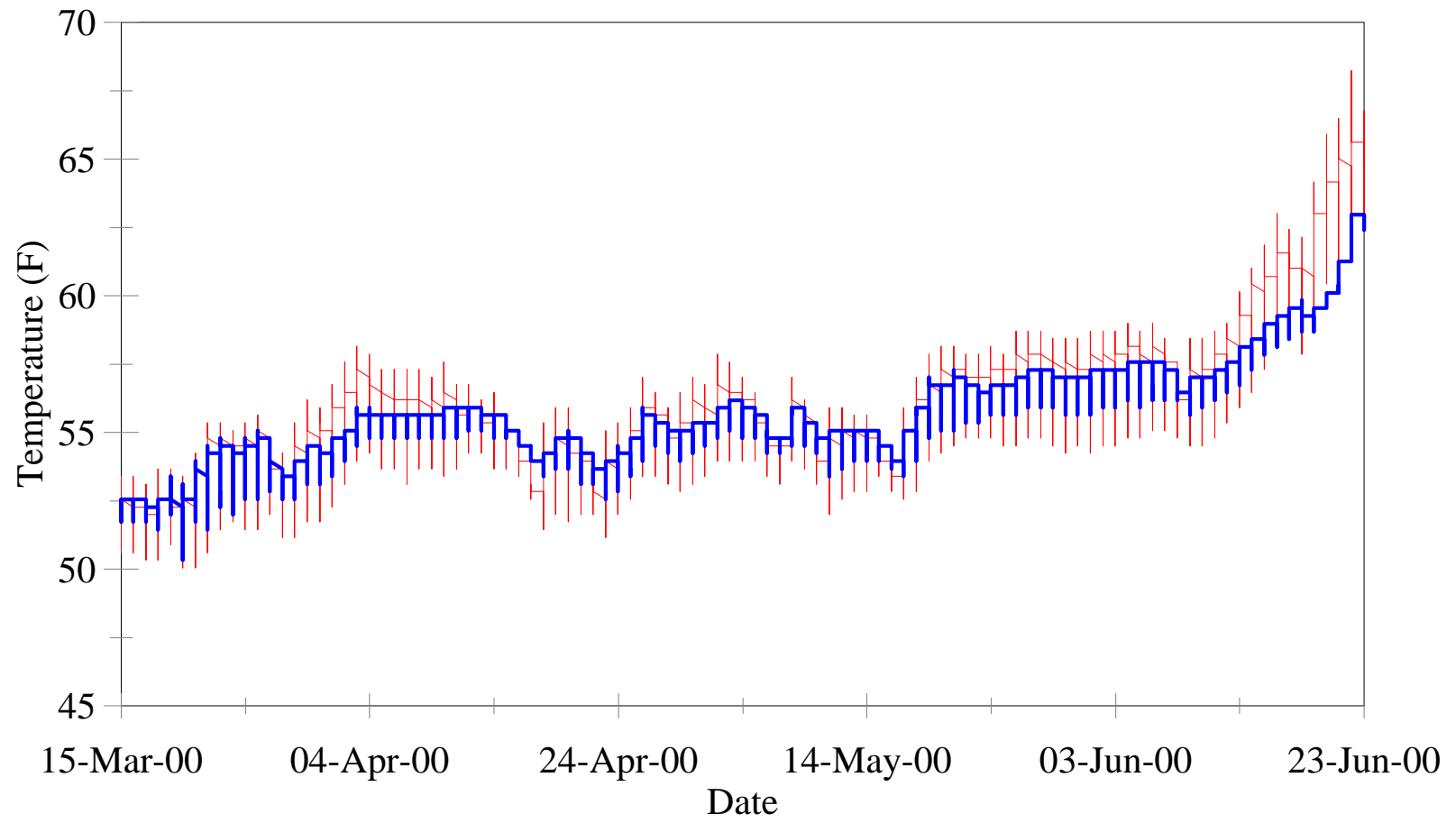
R76 P1



R76 P3

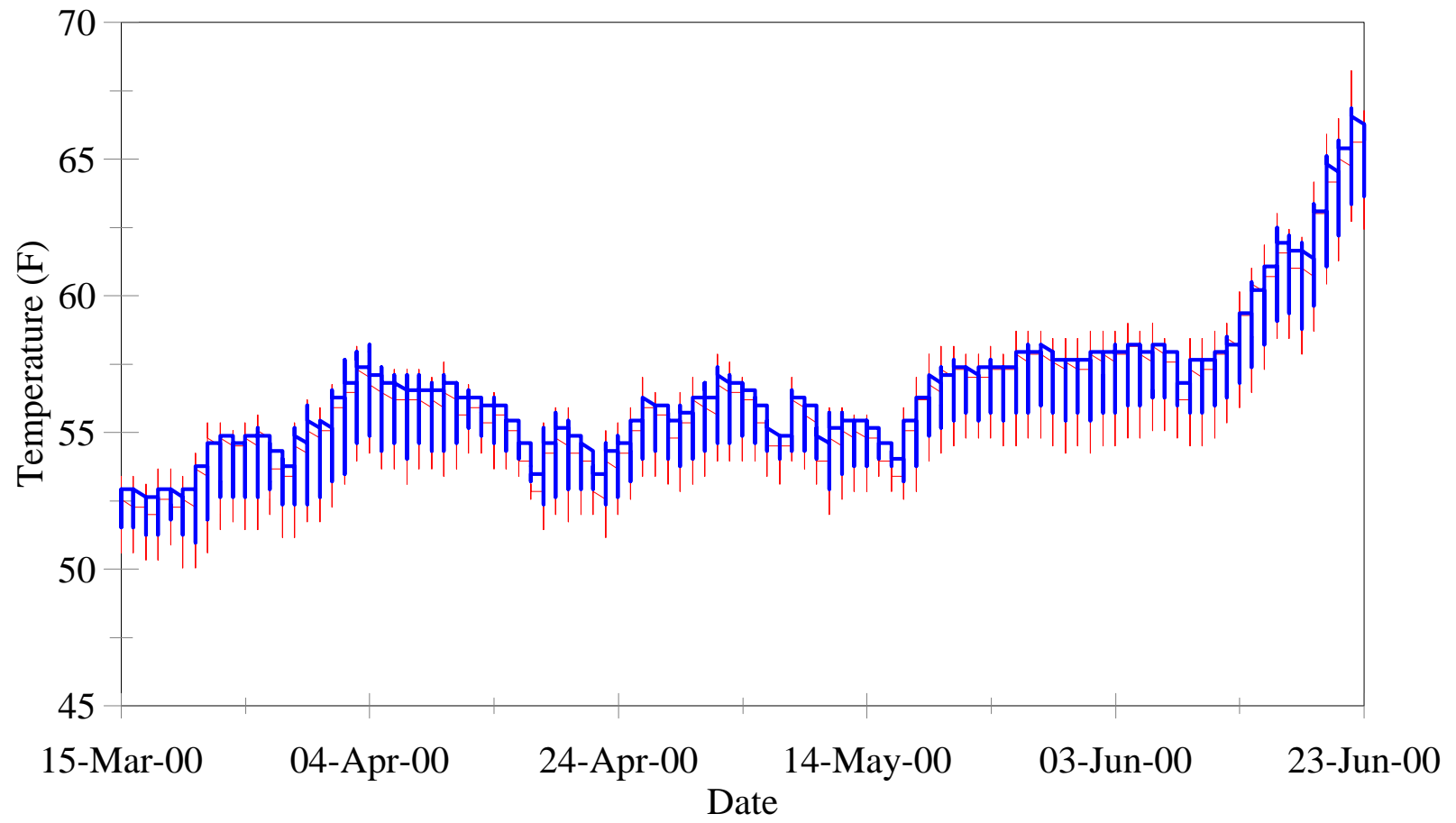


R76 P4



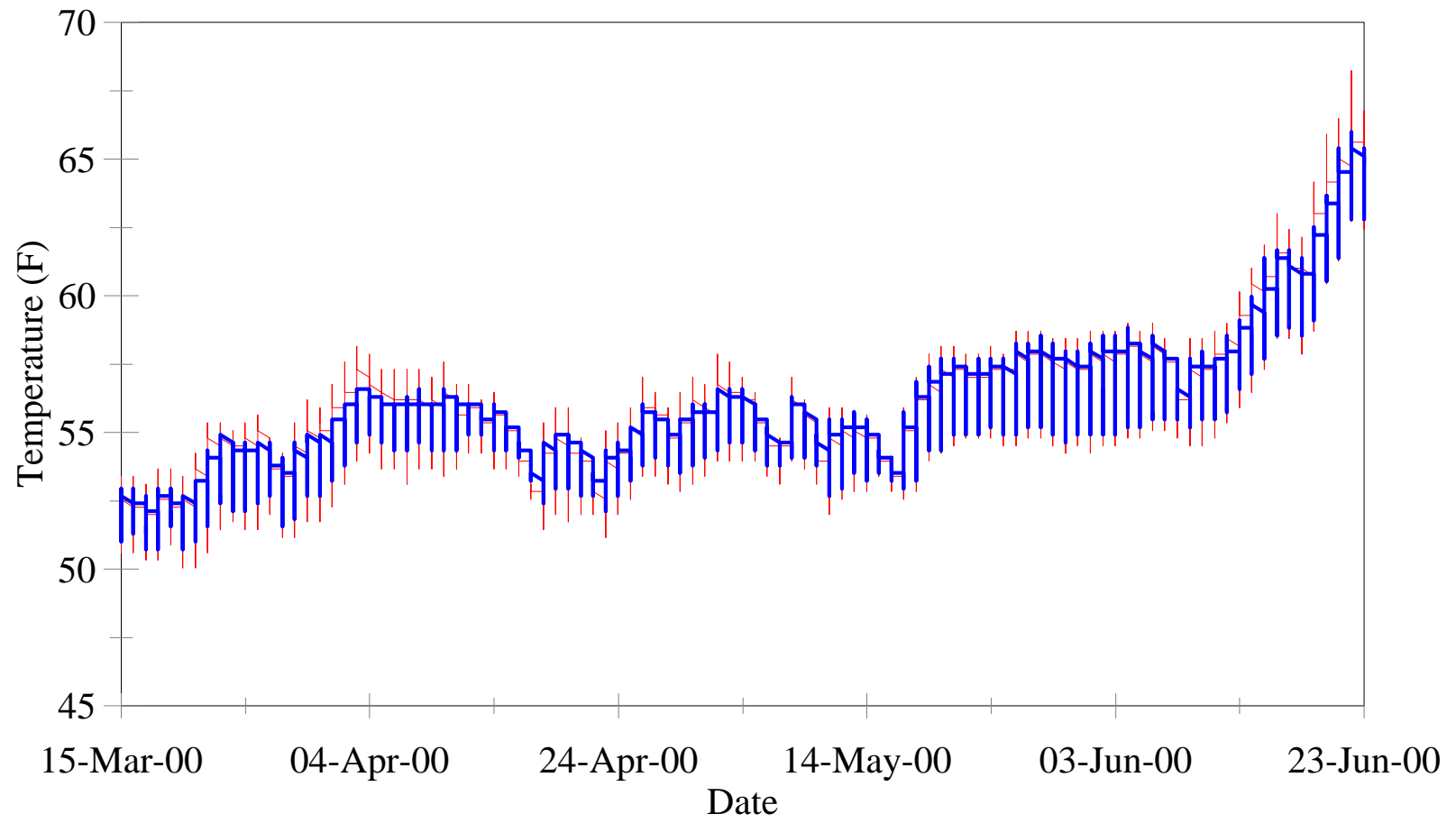
— Surface Temp — Intragravel Temp

R78 P1



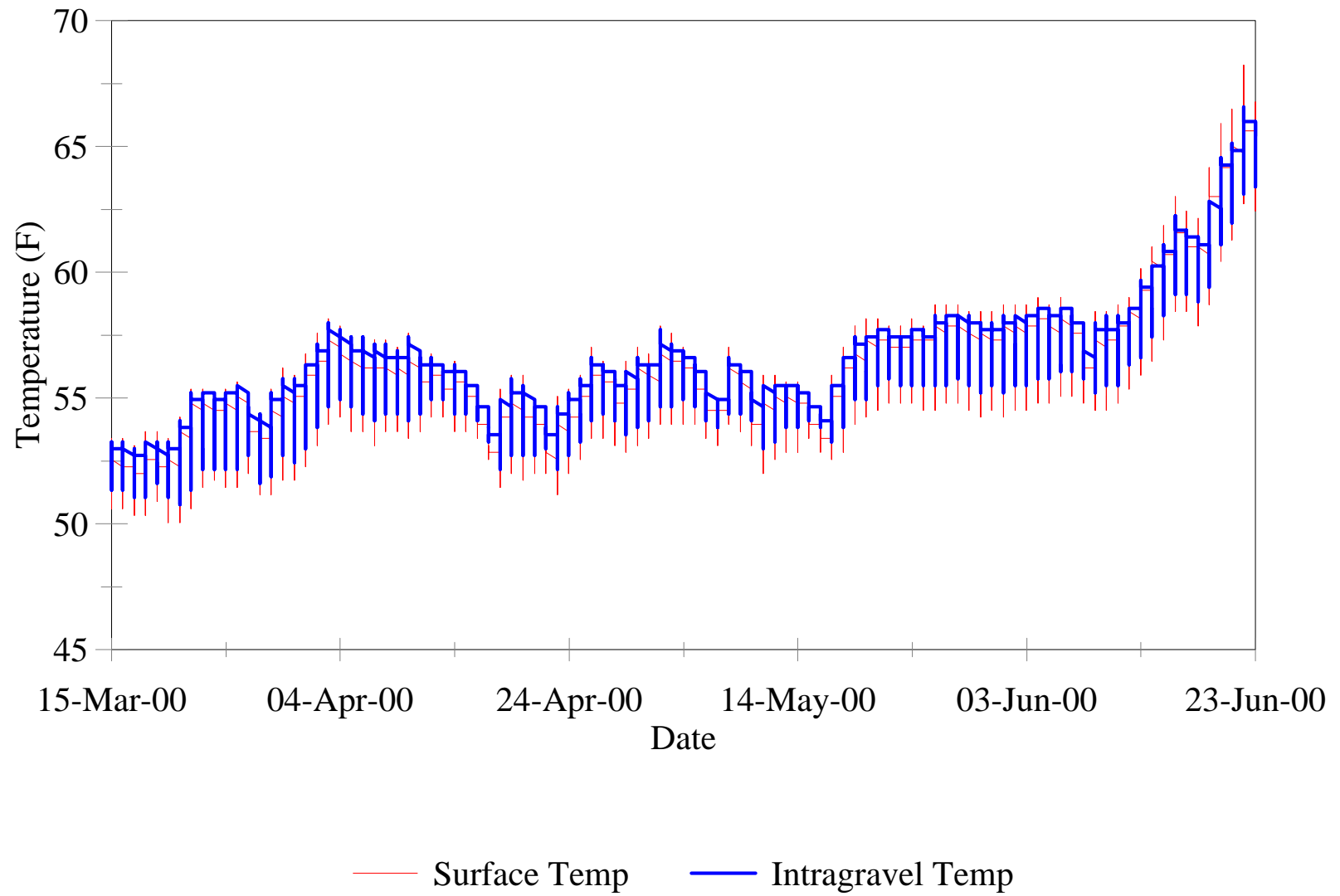
— Surface Temp — Intragravel Temp

R78 P2



— Surface Temp — Intragravel Temp

R78 P3



R78 P4

